THE ROMANCE OF REALITY

BEVERLY L. CLARKE

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THE BEAUTIES AND MYSTERIES OF MODERN SCIENCE

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THE ROMANCE OF REALITY

The Beauties and Mysteries of Modern Science

BY

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PREFACE

This is not an "outline", nor yet a "story" of Science: these words imply a certain completeness and an exhaustiveness in treatment, to which the present work cannot lay claim.

Science, because it deals with matter, and because matter can often be most unæsthetic, has acquired rather a bad name among people whose criteria for real value are beauty, symmetry, and romance. The assumption seems to be that a department of activity which, like Science, produces the fertilizer factory and the gas works, and gives rise to shrapnel, poison gas, and patent medicines, must certainly lie toward the lower end of the scale in which the department producing art, literature, and music heads the list. "Materialist" is an epithet of utter scorn, and Science is supposed to be an exceedingly cold-blooded and glamourless affair.

It is the writer's personal feeling that this assumption is altogether unwarranted. It seems to him that the method, the attitude, the spirit, and even the subject-matter of Science are characterized above all by beauty and symmetry, and that the picture which Science has evolved of the nature of the Universe should rank, by virtue of its grandeur and its delicacy of execution, with the greatest masterpieces of those arts which scorn it.

In the following pages the general outlines of this most magnificent of masterpieces have been sketched. Here and there the detail has been filled in, but the emphasis has always been on the picture as a whole rather than on detail. The author has not thought it consistent with his aim to accompany this delineation with much matter of an argumentative nature; and if the romance of reality does not appear spontaneously, the artist and not the model will be to blame.

The author desires to acknowledge his indebtedness to Dr. E. E. Slosson for encouragement and valuable suggestions in the early stages of the book, and to Professor L. B. Becking, Stanford University, for critical reading of some of the chapters. Especial acknowledgment should be made to Dr. Slosson's little book, "Easy Lessons in Einstein," from which much of the material for the chapters on Relativity was drawn.

BEVERLY L. CLARKE.

New York, April, 1927.

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THE ROMANCE OF REALITY

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CHAPTER I

THE ROMANCE OF REALITY

"How weary, stale, flat and unprofitable," complained Hamlet,

"Seem to me all the uses of this world!

Fie on't; ah fie! 'tis an unweeded garden,

That grows to seed; things rank and gross in nature

Possess it merely."

And taking its cue from these immortal lines of the Melancholy Dane, civilization has surrounded itself with all manner of schemes and devices designed to make us forget for a brief space this drab world, and to waft us gently into the vast uncertain realm of unreality. Life for most of us is a grind, an enslavement to mechanism and routine. The inexorable force of gravity chains us to the earth. Complicated social systems enmesh us with the affairs of others; and the wee small voice that comes from an empty stomach is more potent as a motive and a cue to action than the more widely advertised vocal effort of a troubled conscience.

It seems that we simply have to escape now and then from reality. To this end we have evolved our

theater and our movies, our short story and our novel—all designed to assist us in shaking off the shackles for a while. Young writers are advised by the wise ones to write their stories about European royalty if they want to be sure of interesting American audiences. The American business man likes to read about the Prince of Wales because that young gentleman represents to him something unreal and hence glamorous and fascinating. The Queen of Rumania complained that one of the unrealized objects of her American visit was to learn something of the ordinary American family; *that* represented unreality to her. One of our most successful writers of stories of the blood-curdling Western type has never been West of Pittsburg and has never seen any cowboy but Will Rogers. He is well off and tours Europe frequently but he is afraid to go West because it might become real to him and his future writings would lack the enchantment that is lent by distance.

This strong urge to get away from reality is at the bottom of much that is curious in human behavior. Clothes, and particularly women's clothes, are all designed with a view to making us look like what we aren't. In transient moments of straight thinking a man knows himself as a bizarre and oddly shaped structure of unæsthetic bones and inelegant internal organs, loosely enclosed by flabby skin and topped off by that preposterous organ known as the head; the naked truth appalls him—and so he applies landscape gardening to his hair and whiskers or else opposes nature by shaving the latter off entirely, and covers himself from the neck down-

wards with garments which would give an entirely erroneous idea of the human form and texture to an observer who had no other source of information. And yet, be it remarked, there exists no such observer. Nobody is fooled, least of all the man himself.

The ladies are more frank, that is they come nearer than men do to admitting to themselves and others that they really look like they do and everybody else knows they do. Curiously enough, with the more deadly of the species the camouflage begins with the neck and works up—just opposite to the vogue for men. Modern husbands permit and in most cases encourage their wives to make free use of cosmetics; they know full well that nature never made lips as red, skin as white or hair as decorative as the corner beauty parlor can turn them out, but they have seen nature's best work over the breakfast table and all scruples are dissolved.

But it must not be overdone. The illusion must be untainted by any trace of the means employed. Among people of refinement the sin is not to use cosmetics, but rather to use them inexpertly. The husbands say, "Go as far as you like, but make it look *real.*" That's the crux of the matter. It must look real. Although everybody concerned knows that it is artificial, it must *appear* real. The lady fondly imagines that she is beautiful and the husband feasts his eyes on her with pride, although he has looked at her over the grapefruit and she has seen herself in the mirror and they both may know the facts to be otherwise.

Why all these puerile attempts to get away from

things, this pronounced aversion on the part of us all to facing cold facts? The key to the answer lies in this name—"cold facts"—that custom has given to material things. It is considered, indeed it seems almost intuitional or instinctive with us to consider, that facts are innately and essentially "cold." By which we mean that they are altogether lacking in that diaphanous quality called romance; that they are hard and firm and unyielding like steel, whereas what we want is something that stimulates the senses and gives wings—though waxen ones, alas!—to the soul, like a fresh-blown rose, or a bit of literature that is subtly and beautifully wrought.

If facts are cold, and facts represent the raw stuff of reality, then reality is cold and uninteresting, and the title of this book—The Romance of Reality—stands convicted as a contradiction in terms. The writer thinks otherwise; that is why he has written the book. He believes that the more a fact is isolated and considered apart from other facts, the colder it gets; that, on the other hand, the more facts are thought of not as things in themselves but as tiles that make up the gorgeous mosaic of Science, the warmer they become. The brick and stone of which a cathedral is constructed may well be left to the day laborer, but the cathedral itself, by its very beauty, is supposed to call down the Spirit of God.

Philosophy is concerned with reality. Its object is to understand the universe in its entirety, with all its ramifications and implications. It tries to see the great scheme of things, what it all means, to fathom the divine plan. No small part of its effort

is directed towards what we term Science. Science, in this limited sense, means the study of matter, its forms and transformations and the laws of its behavior. Less than a century ago what we now call Science was termed Natural Philosophy, emphasizing its proper place as a branch of Philosophy. Nowadays, in the midst of the Industrial Age, the philosophic side is often forgot, and the word Science brings up pictures of steel mills and coal tar. We shall be interested, in this book, only incidentally with this aspect. Our chief purpose is to give some hint of the great scheme of things, of the beauty of form and structure which becomes more and more the dazzling attribute of science as we succeed in taking the various separate branches of Science out of the pigeonholes where convenience has placed them and glimpse how they all fit together into a whole of which the grandeur soon transcends the intellect and carries the emotions and the soul towards the dizzy heights of ecstacy.

CHAPTER II

THE GARDEN DREAMER

The underlying idea of Evolution is that the changes which take place in plants and animals from generation to generation, tend to produce a race with a better chance of surviving, prospering and flourishing than all others that have gone before. Whether this is brought about by the active and beneficent intervention of some super-intelligence, or whether it is simply the inevitable operation of some vast automatic mechanism without present intelligent guidance, we cannot say. But, without venturing on this controversial ground, and without unjustified vanity, we can affirm that the human being of to-day seems to be Evolution's latest and, thus far, most successful achievement.

Evolution proceeds like the growth of a tree. From the seed springs the main trunk, growing ever upwards; the tree is drawn irresistibly towards the sun. Growth has not gone very far before a branch shoots out to the side, subtly preferring a devious route to a straight one. Many such branches start out, but the majority of them grow only a short distance and then stop; it is as if they saw their error and became resigned to failure. But sometimes one of the branches grows large and long: eventually, by force of this insistent leadership, the whole tree

turns in that direction and reaches a spot of sunlight, in cases where it could not have done so by adhering to the straight and narrow. As often, opinion seems to be divided, and the trunk of the tree splits into two main branches which follow different and tortuous paths to a place in the sun.

There seem to be similar things going on in the animal evolution. The goal is perfection, if we understand by the perfect animal the one which is best fitted for life on the earth. Numerous false starts are made, which are comparable to the small ineffectual branches on the tree. But now and again a particular sort of change in the animal appears to be what was needed, and the whole current of evolution turns and flows in this direction. Sometimes, also, matters have narrowed down, not to a single, but to two or three main branches.

In the evolutionary struggle to perfect the animal there came a period when the apes represented the highest type of development. If we may for a moment compare the executive intelligence in evolution to a board of directors, we may say that a special meeting was called for the purpose of deciding upon future policy. About half of the members of the board held the opinion that attention should be concentrated in the future on developing a race of strong and rugged bodies, adapted by their physical strength, by their sturdy construction, and by their fierceness, for combating extremes of climate and for holding their own against other animals.

But the other half of the directorate had the glimmering of an idea which was entirely new to

Evolution. It was their contention that the bodies of the apes should be left alone and an effort made to improve their thinking mechanism, so that instead of trusting always to mere physical force they might gradually acquire the capacity to concoct schemes and plans by the use of their minds for triumphing over nature and other animals. In other words, the idea was for the mind to develop at the expense of the body, in the belief that the additional faculties thus acquired would much more than counterbalance the loss of physical prowess.

Thus two main branches started out to conquer the world, the apes with their brute bodies covered with hair and designed for fighting, and the strain that was later to become Man, with its weaker and softer body but its rapidly growing mind. We all know what happened. The apes are still apes, still live in trees and depend on strong muscles, sharp claws, and general physical agility for sustenance and survival; but with all this they are fast becoming extinct: the branch has had its try and it must be written down as a failure.

But here we have, on the other hand, this successful offshoot of Evolution, this remarkable excrescence called Man. A body which is pitifully inadequate to combative existence in the literal sense, tender skin, soft and flabby muscles, slight endurance and comparative physical awkwardness: this is one side of Man. A bull or a bear is many times stronger than any man. Even Gene Tunney in the lions' den would not have one chance in a million. And as far as fleetness of foot is concerned, Nurmi, the Finnish marathon champion could never hope to

keep up with a fox or even a mongrel dog in an open race.

What are our compensations for being weaklings? Look about us at our fields of cultivated crops; observe our houses, our cities, and our highly developed social life; observe our motor cars, our steamships, our locomotives and our airplanes, our telephone, radio, telegraph, our telescopes for taking our eyes into the heavens—all products of Man's ingenuity which seems to tend towards the virtual annihilation of time and space, the dissolution for Man of these spatial and temporal restrictions that cramp him.

With a langorous tap of his velvet paw a tiger could crush a hunter, but the intellect of Man has provided the hunter with a rifle from which a single bullet will reduce the beast to inertia. Where is the animal which has developed any weapon for defence or offence even remotely comparable to the rifle? Man has constructed powerful automobiles, swift airplanes, graceful ships and submarines, with which it is a simple matter to beat the fox, the eagle, and the speediest of fish at their own games.

That is our compensation: the possession of an intellect vastly superior to that of any other living thing; an intellect that gives an alien cunning to our artless-seeming hands, and dresses our slightest constructive effort with a witchcraft that must seem indeed godlike to the lesser minds of animals.

Implied in this practical attribute of intellect, but underlying and sustaining and utterly transcending it, is the quality in mind which enables it and impels it to seek beauty and truth in all things, to view life

and all that life implies with a panoramic breadth of vision, having synthesis as its goal and reaching towards perfection of understanding. This attribute of mind is so altogether foreign to every other being but Man that it stands out squarely as the one and unique possession of the human animal which differentiates him sharply from all other forms of life. It is our most valuable possession and as such deserves more serious attention, use, and development than any other side of us.

Let us be more definite; let us see how this peculiar intellectual possession of ours motivates our thoughts and our actions, and casts our personalities from a mold which compels us to strive towards perfection. Animals, in their wild fight for food and shelter, are never tortured by thoughts about themselves, why they are here and where they are going; or whether this or that is right or wrong, true or false, good or bad. Only in Aesop's Fables are the minds of animals concerned with such thoughts; and it is the very unreality of these Fables that gives them their charm. Animals are not so constructed mentally. They are content to accept things as they are, never to reflect upon the past nor to dream about the future; they live, without conscious will or purpose, only for the present comfort.

Not so with Man. He is by nature perpetually engrossed in speculation, attempts at reasoning, planning, relating cause and effect, solving mysteries, and peering strainedly now into the dark obscurities of the past and now through an imagined keyhole in the heavy portals of the future. It is ingrained in

our nature thus to occupy ourselves; religion, science, philosophy are but manifestations of this tendency.

It is futile for us to strive to drown these impulses to dreaming and speculation; they are the very essence of our being. The wise man is one who will give himself over to wonder and curiosity, who will nurture and encourage the urge to know, and who will unreservedly devote his intellectual life to enlarging his mind and expanding his soul.

But the great question concerns the precise mechanism, the *modus operandi,* of leading ourselves towards this goal, of selecting an approach to the great problems of vital thought which will be efficient, logical, and consistent with the nature both of thought and of the world. Shall we attain our end by selecting an easy chair, closing our eyes and wrinkling our brows in thought? The chances are that after a brief and painful effort we would fall asleep. No, there must be another way.

Let the reader imagine that he awakens from a heavy sleep to find himself in a brilliant and beautiful garden, of which the loveliness awes and the strangeness prods the curiosity. Let the dreamer be assumed a mentally normal man, experiencing and reacting to the same sorts of stimuli as guide his thoughts and his actions when awake on the earth; but assume in addition that from the tables of his memory have been wiped away all traces of his earthly existence, that he remembers nothing of his past and is entirely like a child which is born into the world with matured mental faculties.

What would the dreamer do and what would his

first thoughts be? As soon as the natural fear and confusion had subsided, he would acquire certain general information about his new state. He would learn that he was there in the garden to stay, that he could no more get out of it than he formerly could have jumped off the earth. Resting from the excitement in a shady spot under the trees, certain questions would arise in his mind: "What shall I do while here in this garden? How shall I pass my time? How ought I to act so as to obtain the greatest possible satisfaction out of my life here? What constitutes the 'good life' here for me?"

After these questions of a practical and immediate nature would follow others of more abstract character: "What power sent me here? What is this place and what is its relation to the world from which I came?"

Suppose now that he gradually learned from things he saw and things told him that he was not to remain in the beautiful garden forever; that finally there was to come a time when he would be compelled to go away. Then again he would find his shady spot, and more questions would come: "Where am I going when I leave the garden? Why do I have to go? Am I really going to some other place, or shall I simply cease to exist?"

To answer these questions the dreamer would devote every effort. They would seem to him the most important thing in his world. He would soon find, however, that, think as hard as he might, he could not find the answers as long as he remained in the comfortable spot under the trees. In going over the questions he had asked himself, it would

seem at first quite hopeless to answer them. Of each one he would say, "It sounds easy, but I can't think how to go about finding the answer."

But after a while he looks hard at one of his questions, "What is this place and how does it compare with the world from which I came?" . . . "Ah!" he says to himself, "that looks a little more promising. I can at least try to answer that. Let's see, now! If I want to learn something about this garden, the thing to do is to start studying the garden and the things in it."

And so he starts. He studies the plants, the strange flowers, the tall grasses, and the spreading trees which are all new to him. He discovers queer stones in the earth, and strange colored waters in the streams. He wonders why the rocks do not grow like the plants, and tries to find out if the plants are made of the same thing as the stones. He studies the other people in the garden, and attempts to discover what makes them different from the plants and the stones and waters which do not move and talk and think. He becomes interested in the size and shape of his garden and makes many maps and drawings. It occurs to him that there may be other beautiful gardens like this one, and he tries to find out where they are and how many. He even studies the stars and the sun and moon through telescopes in an attempt to answer some of his questions.

And then the miracle happens. When finally the dreamer is in sight of an answer to his question about the garden itself, it suddenly seems to him that all his other questions begin to look simpler and less discouraging. And when again he seeks out his

shady nook, he finds himself able to think about them now with less mental labor; it appears that during the course of his more practical investigations vague suggestions and ideas have come to him which now crystallize and acquire the character of vulnerable points in the more abstract question through which he can make an entry and secure a foothold.

The moral of the allegory is too obvious to require extended elaboration. All of us human beings are like the dreamer in his garden; our garden is this world into which we have been born, having no more clew to the answers to the major interrogations which beat upon our brains and torture our hearts than had the garden stranger.

Early in infancy we begin to be conscious of what goes on about us, of houses and trees and rivers, of dogs and cats, and birds that soar in the air. Very slowly we come to know all the many things which go to make up this odd and interesting world which is our home.

We soon learn that we are bound here on this earth for a lifetime, as the dreamer was compelled to remain in his garden. And although as a small child we may revel in the thrilling fairy tales about trips to the moon, and may spend long happy hours reading the delightful adventures of Alice in a wonderland world very little like that with which we are acquainted in everyday life, we soon cease to believe in the real existence of such things, and learn to accept as the actual world the things we see and feel when we are awake, and not the flimsy dreamlands our fancy creates.

As we grow a little older, we begin to find a subject for much wonderment in what we call death. It seems strange to us that each human being is here on the earth for only a short lifetime, and that people now living must cease suddenly to move and talk and feel and think, and become as lifeless as a stone, whereupon their cold bodies are buried in the ground "to return to the dust from which they sprang." It seems to us that death is essentially sad. And yet we reflect that it would not be sad at all if death, instead of being simply a ceasing to live, were but a journey from one garden to another, perhaps even a more beautiful and desirable place to live.

And so as with the dreamer in his garden, life comes to mean to us a series of questions: "Where did I come from? Where am I going? What ought I to do while I am here? What is the nature of this earth where I now am?"

Whether we wish to or not we cannot wholly avoid or sublimate this interrogatory texture of our minds. Futile attempts at sublimation, motivated variously, or half-conscious efforts at vicarious reliefs, are all too common; this is probably at the bottom of a large portion of our psychological complexes.

How much better, then, not to try to avoid these questions, since we cannot escape them. By some of us it is sincerely believed that the human mind has the power to obtain a fairly satisfactory answer to the questions before it. Furthermore, it follows immediately that the first step in the proper answer to the question about what we ought to do while

here is to make this attempt to answer these questions. The degree of success in individual cases is problematical, but few can deny that the lifetime of serious intellectual effort involved must in itself stimulate the mind, enrich the life, and elevate the soul. There are not many of us who are so situated in life that we can do nothing but sit down and ponder these questions; few of us really want to do this. There is a big side of our lives where we play the parts of bankers, policemen, or storekeepers. But no matter what our occupation or whether we live in New York, Paris, or the Fiji Isles, there is a certain energy resident in our spirit which can and should be directed towards more serious and less "practical" ends. The artist, the creator of literature, the musician, these individuals are using the same type of energy which it is here proposed should be turned by those of us who are less fortunate, towards our interrogations.

But how to begin? Here we come back to the situation of the garden dreamer. He found that the more abstract questions about origin and destiny were as if smoothly spherical and self-sufficient, discouraging penetration and offering no obvious handles by which they could be grasped. And so he turned to his question about the garden itself and found it possible by application and hard work gradually to acquire knowledge of the physical side of himself and his environment. And with this knowledge the questions of origin and destiny relaxed their menacing miens and came more within the range of attack.

Thus it is that we are here suggesting that a con-

sideration of the world we live in, a consideration, in other words, of the facts and broad underlying ideas of Science, is the logical precursor of, if not an absolute prerequisite to, an intelligent consideration of the problems of philosophy. The following chapters in this book constitute an attempt to place these facts and ideas before the reader, not in a practical form or with utilitarian ends, but from the viewpoint of their bearing on philosophy, culture, and serious thought.

CHAPTER III

BUILDING STONES OF THE UNIVERSE

Two great cities, as New York and San Francisco, are "connected" to each other in a number of ways. There is, for example, the long-distance telephone, over which people in the one city can hold conversations with those in the other. Again, railroads join the two cities. Steamship lines, transcontinental highways, radio, the telegraph and postal services all serve as connecting links between these two great centers of population, commerce, and culture at opposite ends of our country.

Thus it is possible for the people of San Francisco to learn a very great deal about New York, even if they never leave their own city.

But let us try to picture what would happen if the railroads, the steamships, the telephone and telegraph, the mail service and the radio, should suddenly cease to operate and the transcontinental highways be destroyed. In such a case a man in San Francisco would have no way whatsoever of learning things about New York.

In a similar sense all human beings may be said to be "connected" to the world by a number of links, which are strictly comparable to the railroads, steamships, etc., which are bonds between the two cities. These links which give us contact with materiality we immediately recognize as our

JOHANN JACOB BERZELIUS (1779-1848)

Swedish chemist. From assistant to a country druggist he became one of the greatest scientists of his day. Perfected methods for the analysis of chemical substances, and introduced the present system of chemical symbols and nomenclature.

"senses." The major senses comprise the physiological arrangements in our bodies for seeing, hearing, and smelling, and the less localized mechanisms for the sensations of pressure and of temperature differences. Solely through these senses do we become conscious of things and events which occur outside of our bodies. There is, indeed, one accredited school of thought which maintains that the human mind has no resources whatever within itself, that it is entirely dependent upon contact with materiality for its functioning; this is equivalent to dislodging the intellect from its accustomed place at the fountainhead of consciousness and ascribing to it the simple rôle of a clearing house for sensations. This may be distasteful to us if we feel the Kantian tendency to assign a quality to mind which transcends all matter; but the fact that sober philosophers see fit to argue it indicates, at least, how closely we are dependent upon our sensations for stimuli to action.

A man who is blind is at a great disadvantage. If he should lose, at the same time, his hearing, his ability to smell, and his tactile and temperature senses, he would be in a very bad state indeed. For then he would be entirely shut off from communication with the world. He would be in an even worse condition than the man in San Francisco when all the links that connected him to New York had been severed. For the San Franciscan could at least talk and read and thus learn a great deal of what was known about New York before the catastrophe—something which the unfortunate man who has lost all his senses could not do.

Now the world with which we are connected through our organs of sense is made up of two kinds of "things." One of these is what we ordinarily speak of as a thing, that is, whatever we can see or feel or touch or which has weight. We call this kind of "thing" *matter*. Absolutely everything one can mention which can be seen or felt or smelled or touched is matter—a nail, a chair, a tree, a dish, water, our arm, the body of a man. Air is matter, for although we cannot see it or smell it, we can certainly feel it. Who has not shivered in a winter wind? Well, a wind is nothing but air moving.

And speaking of the air moving reminds us of the second kind of "thing" which, together with matter, makes up this world. This is somewhat more difficult to grasp than matter. Consider a man sitting in a chair reading a book. If the man is healthy and normal, he knows very well that if he wanted to, he could get up and walk across the room. Although he is sitting perfectly still, he nevertheless has the *power* to do something.

Now consider a baseball which has just been thrown. If the pitcher's aim was good, the ball moves gracefully through the air and finally comes to rest on the grass some distance away, doing no harm to anything or anybody. But suppose that while the ball is on its little journey through the air, a wicked magician turns the neighboring house around so that the plate glass of the front window is directly in the path of the ball. The reader probably knows from sad boyhood experience what would happen. The glass would be smashed to smithereens. And from this we see that the inno-

cent-looking ball can do a lot of things which perhaps it doesn't do. If one takes a photograph of the baseball lying on the grass, and another picture of it during an instant of its flight through the air, one will not be able to find any difference in the appearance of the ball in the two pictures. And yet the illustration of the smashed window tells us at once that there is some sort of difference, and a very important one at that.

We who live in New York are so used to electricity, in the forms of light, heat, power for running subways, etc., that we sometimes forget the interesting origin of all this electrical energy. The truth is that it comes, every bit of it, from Niagara Falls. The water is made to turn wheels which work engines. The engines generate the electric current, which is sent to New York and to other places to be used in the many ways we use electricity to-day. And the strange thing about it is that none of the water is used up. Just as much water flows away at the bottom of the Falls as starts over the top. Furthermore a bottle of the water collected at the top will show absolutely no chemical or other differences from one taken at the bottom. It is exactly the same water and exactly the same amount.

But it is evident that there is really some difference, because the water at the bottom of the Falls will not turn the wheels that work the electric generators, while the water flowing over the Falls will. We thus see that water may possess the ability to *do something,* and yet not be different in appearance from water which will not do that something.

This power to do things which the water and the

baseball possessed, and which matter of any kind may have, is the second half of our world. This ability to do things is called *energy*. The world is made up of matter and energy. Matter and energy are always associated. If there is energy, there must be some piece of matter which has it.

The most striking thing about energy is the many different forms it may have. The baseball and the water both had energy because they were moving. If we stopped the ball with a glass window, it gave up its energy to the window, breaking it. The water of the Falls had a tremendous amount of energy because it was going down hill. The earth, which is a very large mass of matter, attracts or pulls every other piece of matter towards it. It seems as if all matter, if given a chance, will try to get as near to the center of the earth as possible. The farther away it is from the center, the more energy it can exert to approach the center. Thus the water, flowing along a level river-bed, with no chance to get deeper into the earth, was tranquilly useless, because no opportunity offered for the realization of the ambition of all matter to approach the earth's center. But suddenly it comes to a place where there is a steep drop directly downwards. Roaring with glee, it plunges noisily over the brink and speeds with tremendous force until the level ground stops it again. If we put a paddle-wheel in the path of the downward moving water, the water will have to give up some of its energy to the wheel, and the wheel will turn. That is just what is done at Niagara Falls. The energy of the turning wheel is changed by means of suitable machines into

electricity, which is just another kind or form of energy and which is more suitable for certain purposes than the energy of the falling water.

The many different forms which energy may have, such as heat, motion, electricity, etc., we will discuss in a later chapter. Let us now consider some things about matter.

How many really different kinds of matter are there? At first thought, one might be inclined to say that there are as many really different kinds of matter as there are numbers to count them with. But actually this is not true. The number of distinct kinds of matter is very small—something near one hundred.

Suppose we wanted to answer this question for ourselves. We would go about it by collecting a large number of objects which appeared to be quite different from each other. Let us say we have in our collection a piece of wood, a glass of water, some coal, a stone, a lump of iron, and a leaf from a tree. Certainly they all look different.

Suppose we first experiment with the piece of wood. Let us get a knife and cut it up. Then with a better knife let us cut each piece up into still smaller pieces. We can keep this up until we can no longer find knives, or until the pieces are so small that we can no longer see them to continue the chopping process. Now we have made from the original large piece of wood a great number of very much smaller pieces. Look at one of the small pieces closely. Examine it in any way we can think of. Will it burn like wood when we throw it into a fire? Will it float on water as wood does? Is it the same color

as the large piece of wood? In short, is it really the same thing as the wood we started with, and is the only difference the fact that one is small and the other large?

These questions would be answered in the affirmative. The small piece of sawdust *is* actually the same in every way, except in size, as the large piece we began with.

Another interesting question arises here. We have agreed that the little piece of sawdust we selected to examine is just like the original wood. Now we ask, is every one of the thousand little particles of wood just like every other one? "Why, of course!" we answer immediately. "Why should they not be all alike?" And this time our guess is correct. They are indeed all alike, just as one would expect.

Now let us go further. Since we have no knife fine enough, and since our eyes cannot see such small objects clearly, we will have to stop chopping up the pieces of wood when we reach a certain point. Now right here is where we stop using our hands and our knives and begin working with our heads. Let us simply suppose that we *did* have knives fine enough, and eyes delicate enough to continue our operation of making still smaller pieces of the wood.

If, just for the sake of the story, we imagine that this is possible, then the two questions come up again. Each time we cut the wood into smaller pieces, we would stop and examine a piece and compare it with the original large block, to decide if it is still the same, and if the only difference is still in size. Also, as before, we would seek to discover if the small pieces continue to be alike in every way.

Our answer for a long time would be the same as after the first cutting up. By producing a large number of small pieces from the one large piece of wood we have changed the wood in no way except in size. But after a great amount of work and a very long time, when we would have actually millions of small particles of wood so minute that the eyes could never hope to see them individually, there would finally arrive a time when our examination of the pieces would tell a different story. Examination of one of the very small particles which we would now have would disclose that it is *not at all* like the original wood. More than that, if we picked up several of the particles we would be surprised to learn that *they* are now *not all alike.*

Suppose we sorted out the several kinds of particles we now have, and arranged them in series of piles, each pile containing particles which are exactly alike. As each pile grew larger there would come finally a point where we would have an amount of each large enough to handle and study. One thing we would notice immediately. Of the three different piles we now have, two of them are *gases.* They are quite invisible to our eyes, having no color, and are also without odor. In fact we might have a somewhat difficult time proving that there was anything there at all. It could be done, however; for example, by collecting the gas in a bottle, weighing it, and then drawing the gas out and weighing the empty bottle. The weight of the bottle and the gas together would be greater than that of the bottle alone, thus showing that the gas has weight and

therefore is as much matter as air is, although we can see neither of them.

It would be easy to show that the two gases we have are really different, and not simply two piles of the same gas. For if we struck a match to one of them it would burst into flame, while the other would not do this.

Besides the two gases we have a third kind of distinct thing, obtained by dividing up the wood. On turning our attention to this we find it to be a black solid substance, looking suspiciously like coal. As a matter of fact, it is exactly the same as coal would be if it were perfectly pure.

We started out to find how many different kinds of matter there are. At first thought, it might appear that, since wood, which we thought to be one kind of matter, is really made up of three kinds, there are, therefore, even more separate varieties than we had believed. We might even be tempted to start in on the two gases and the black stuff and try in the same way to divide each of them up into several other kinds of things. There is no reason why we shouldn't try this. But to save time and trouble let us take the word of those who know that we would never have any success. Divide up the coal-like substance, or each of the gases, as finely as you cared to—you would never get anything out of them different from what you began with.

So it thus appears that the two gases and the black material we obtained from the wood are different in one very important respect from the original wood. The difference is like that between a toy house of red, white, and blue blocks and the blocks themselves. Tearing down the house and arranging

all the similar blocks in piles as we did with the wood particles, we find that the house is of course no longer there. The house depends upon the blocks for its existence. But the blocks are different; they exist of themselves and depend on nothing.

Thus we were able to divide the piece of wood into three separate and different kinds of matter—as we tore down the house and got three different kinds of blocks. But we have also learned that we cannot do the same thing to any one of the two gases or to the black substance. We could *put them together*—if we knew how—to make the wood again. But we *cannot take one of them apart* and make anything else.

If we should examine a piece of glass in the same way we worked with the wood, our experiment would have a similar result. If we ground the glass so very fine that it was like talcum powder, each particle of the glass dust would be exactly the same as the large piece of glass we started with. But as with the wood, we would finally come to a point where we could no longer divide up a small particle of glass dust and still have glass. In this case also, if we arranged the different kinds of matter obtained from the glass into piles, we would have three piles. One would be a soft solid which would start burning if we threw water on it, but would not burn if we touched a match to it? Another would be a very hard, black, shiny material like ebony. And the third would be a gas. This gas would prove, on examination, to be exactly the same as one of the gases obtained from the wood.

By examining the wood and the glass we have now found five different varieties of matter which we

cannot divide up into other varieties. If we took the water next, we would obtain from it two gases, and these two would be in every respect the same as the two from the wood.

Imagine that every different object in the world were studied as we have studied the wood, the glass, and the water. This has really been done. Not, however, by the method we have described, but by others which need not concern us here.

Suppose that after the investigation of each object, the separate different kinds of matter were placed in piles. Then these piles would be compared with all the other piles which had previously been obtained. If one of the new ones was found to be the same as one of the old ones, the two would be placed together and considered as one pile.

We can now understand the answer to the question about how many different kinds of matter there are in the world. When it was stated that there are a few under one hundred, it was meant simply that after the above study of all the objects in the world had been completed and the piles counted, there would be this number.

Now it may seem strange that out of this small number of kinds of matter are constructed all the various things which meet our eyes wherever we look. Try counting them. There's wood, and glass, and water, and paper, and cloth, and meat, and dirt, and paint, and metals—but what's the use? It would take us several lifetimes to name them all. There can be no debating the fact that there are a great many more than one hundred.

When the matter is fully understood, there seems nothing paradoxical about it at all. Suppose we have a lot of red blocks, and some blue ones, and a number of yellow ones—only three kinds of blocks. Consider how many different things we can make out of them by arranging them in different ways. Think how many different kinds of houses we could construct, how we could even lay out complicated models of towns and cities. Again, think of how many entirely different pictures we could paint if we only had three different colors. One would hesitate to set a limit to the number.

In quite the same manner the hundred different kinds of matter, or *elements,* are arranged into the various forms and shapes of the things that make up the physical world and everything in it, even our bodies.

If water is heated sufficiently it turns into steam. If it is cooled enough it becomes ice. Examination of water, ice, and steam, in the same manner as we examined the wood and glass, would show that they are all three built from the same two elements. What is the difference, then, between ice, water, and steam?

To answer this it is only necessary to remember that all we have to do to water to change it to steam is to heat it—that is, to add heat to it. Similarly, to obtain ice from water, we take away heat. Now if we can add heat to water or take heat away from it, it sounds reasonable to say that water *contains* heat. That is what we can say. But we do not mean by that the same as we do by saying that the water contains dirt or sugar. Heat is not matter,

for it has no weight; we cannot put our fingers on it and say, "This is heat." For when we try we find that what we really have our fingers on is some *thing* that is *hot* and not the heat itself. Heat is thus not matter but energy. It is energy because it represents the power to *do something*. Water plus enough heat is steam, and steam will run a locomotive, while the water alone will not.

Now water is a liquid, steam a gas, and ice a solid. The fundamental difference between one and another is the amount of heat energy bound up.

If we examine a piece of lead we find that it is a solid. Heat it, and it becomes a liquid. If then we continue to heat the liquid lead for a long time, it will finally change to a gas—provided the flame is hot enough.

All the objects with which we are acquainted in the world fall in one of these three classes: solid, liquid, or gas. Different things require vastly different amounts of heat to change them into liquids or gases. That explains why, on a Spring day, all the winter ice will have melted to water although the stones will still be solid.

There is, however, no very sharp dividing line between solids and liquids. Often we are very uncertain whether a given substance should be classed as one or the other. We usually mean by a solid object one which will keep its shape no matter what sort of vessel we place it in. If, for example, we place a cube of wood in a round dish, we know that the wood will remain a cube and will not become round just because it is in a dish of that shape. A liquid, on the other hand, is something which *will*

Dimitri Ivanovitch Mendelejeff (1834-1907)
Russian chemist. He arranged the chemical elements in a table according to their characteristics, and his work along this line paved the way for the modern science of atomic architecture.

assume the shape of the vessel in which it is placed. Water is a good example and we are familiar with its conduct in this respect. A liquid is further known by the fact that its surface, in an open dish, is always level with the ground.

If, however, we place a cubical block of jelly in a round dish, at first the jelly will act as the wood did, that is, it will remain a cube and not become round. After it stands for some time, however, it very slowly begins to collapse and in a few days the jelly has become round like the dish. In this case, then, whether we ought to call gelatin a solid or a liquid must remain an open question. As a matter of fact it makes very little difference, since calling things solids or liquids is only a convenience to help us describe them.

Gases are more definite and there is usually no difficulty in distinguishing them from liquids. If you place a gas in a closed vessel of any shape, it will fill the whole of that vessel no matter how large it is. There will be no free upward surface as there is in the case of liquids.

We may state, in conclusion and by way of summary, that the total number of separate and distinct kinds of matter is very small—about one hundred—and that out of these hundred elements are made all the many different objects of the world.

In the course of any progressive comminution of such a substance as wood we eventually arrive at a particle of wood which has all the characteristics and properties of wood in the mass, but which cannot be further subdivided without losing these characteristics and being resolved into several distinct types

of matter all different from wood. This smallest particle of a substance which retains all the properties of the substance in bulk is known as the *molecule* of wood. A mass of any substance which is appreciable to the senses is simply an aggregation of molecules of that substance.

But we are able to deduce from our imagined experimentation that even a molecule is complex and is made up of several particles of elements. This smallest particle of an element which may be obtained is termed the *atom*. This word atom was chosen to describe what was thought at the time to be the ultimate and indivisible unit of which matter is built, and the meaning of the Greek words from which "atom" is formed is "cannot be divided." But, as we shall see further in this book, this assumption has proved far from correct, and the disruption of atoms into simpler, smaller, and more fundamental units is now a matter of everyday occurrence in the world's scientific laboratories.

We have found that, besides matter, there is something else in the world which always accompanies matter and which is most useful in practical life since it can be made to perform much of our work for us. This *energy* may have a number of different forms, some of which, as heat, are more important than others.

In the following chapter we will discuss the structure of matter more in detail, and will see how we are certain of the existence of particles of matter so small that many millions would be necessary to make a spot large enough to see.

CHAPTER IV

THE BUILDING STONE DISSECTED

From the facts brought out in the preceding chapter, an incomplete picture of the make-up of material objects is now before us. Atoms join to make molecules; molecules join to make the larger masses which we see and feel. The logical next step towards the full understanding of the mechanics of materiality is a consideration of the intimate internal anatomy of the atom itself.

Atoms are of almost unbelievably small size. A row of hydrogen atoms one inch long would consist of about one thousand million individual atoms, and, since the thickness of the line would be only 1/1,000,000,000 of an inch, it would require nearly a million of the rows laid side by side to make a line appreciable to the human eye.

If it staggers the imagination to think of a material object of such a degree of minuteness, it must indeed paralyze this faculty to consider that even the lowly atom is constructed of particles of such a size that 6 million of them, laid in contact in a straight line, would be required to equal the diameter of the hydrogen atom.

These numbers are so vast, and the concepts they inadequately represent so utterly foreign to the content of experience, that cold, bald statements of fact

about the nature of the atom must shed a false and somber shadow of abstruseness over the peculiarly fascinating branch of Science which studies atomic structure. Our intention is to get as far away as possible from this technical side of science, in the belief that it is wholly unnecessary for the gaining of a bird's-eye view of reality. Let us then dissolve away this dark, forbidding shadow by the roseate irradiation of fantasy; let us, in other words, approach the romance of reality by a route which is fantastically unreal.

To this end we shall imagine ourselves in a magic laboratory, equiped with preposterous microscopes which enable us actually to see an atom as the physician is able to see the bacteria that cause disease.

The experiments imagined in the last chapter would require such a magic laboratory for their performance. In those experiments we separated wood into its three elements, which are the two gases, hydrogen and oxygen, and the black solid known to the chemist as carbon. In our fantastic workshop let us now place a single atom of carbon under the microscope and observe its architecture in detail.

We look into the magic microscope, and quickly we turn our eyes away, for we are dizzy and our heads swim from the amazing things we see. The innocent-looking little speck of carbon dust that seemed so dead and motionless now shows itself as constructed of still more minute particles in violent and unbelievably swift motion. The picture we see is that of a very small speck which remains stationary,

with a number of somewhat larger specks flying around it in circles at speeds so high that when we express them in numbers they mean very little to us. The speed of some of these particles is, for example, said to be almost 186,000 miles a second. That by itself means little, but when we say that this speed is such as to take the little particle (the *electron,* it is called) from New York to San Francisco sixty-two times in one second—then we begin to appreciate a little what a tremendous hurry the electron is in to get where he is going—and he's only going around in a circle at that!

This speed of 186,000 miles a second is the speed at which light travels, and we have good reason for believing that nothing in the world can ever go faster than this. Most moving things such as trains, baseballs thrown in the air, and even airplanes, move a great deal slower than this. The little electron flying around the center of the atom is the only thing which approaches very close to the limiting speed. It is very interesting to notice here that the electron, besides being the fastest moving thing in the world, is at the same time the smallest thing in the world when measured by weight.

We customarily look upon certain kinds of matter, for example iron or marble, as being rather solid affairs. We would ordinarily laugh if anyone suggested that a bar of brass is not solid at all but full of holes so small we cannot see them. And yet this is true, as a moment's reflection on what has been said will show. In the first place in the metal bar we have atoms of the metals of which brass is composed (copper and zinc). Each atom is far from

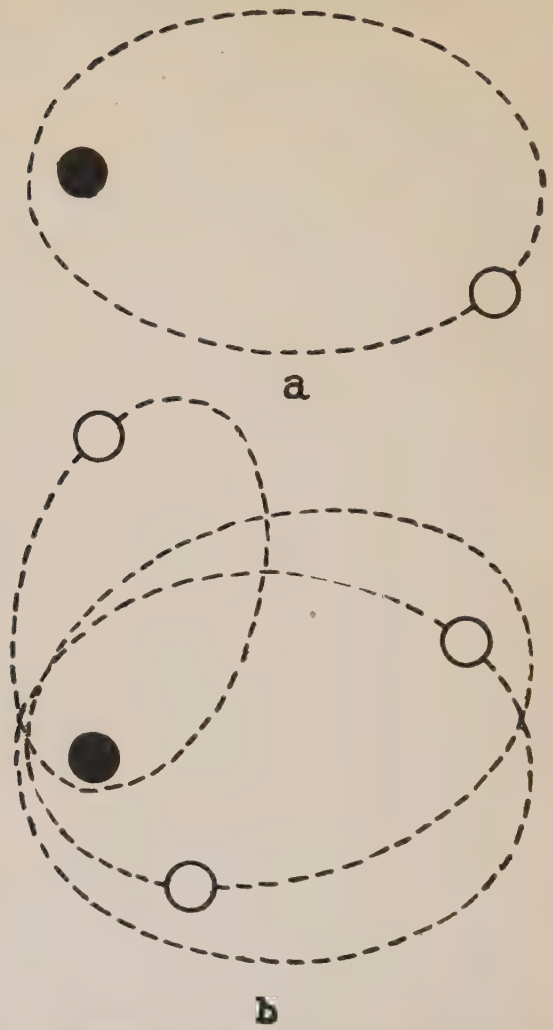


FIG. 1.—*a*. Diagram of the Hydrogen Atom. Black circle represents the electrically positive core; white circles the negative electrons. Dotted line shows one of the many possible paths or orbits of the electron in its revolution about the nucleus. The "size" of the atom varies with the shape of this path, but is of the order of $\frac{1}{100,000,000}$th of a centimeter.

b represents an atom with three electrons (lithium), each revolving in its own orbit.

being a solid ball. In fact it is mainly filled with nothing. A famous scientist recently made a speech on this subject and he chose as his title, "Matter—is there anything in it?" He nearly convinced his audience that there wasn't! The space occupied by the electrons and the central core of an atom together is very small indeed compared to the space filled by the whole atom. That means that there is a great empty void between the ring in which the little electron revolves and the core. The amount of solid matter (electrons plus core) compares to this empty space about as a ship compares in size to the sea on which it is sailing! So we see that the atom is not exactly solid.

Although we are not perfectly sure of the shape of atoms, we have reason for thinking most of them round like a ball. Hence when several atoms are joined to form a molecule they cannot fit closely together. Try it with a few marbles; you will quickly see that this is true. So besides the holes in the atoms themselves, we also have holes between the atoms. And in the same way the molecules, not being cubes like blocks, cannot fit together perfectly, and there is space between them.

We thus arrive at an astonishing picture of a bar of brass as being really quite full of holes. The dimensions of these openings are, however, similar to those of the atoms and electrons, and they are therefore quite invisible.

Our next question will logically concern the architectural difference between the atoms of different elements. We require to know: "If an atom is a central core around which several electrons are fly-

ing, what then is the difference between the ninety-odd atoms?"

The best way to get at an answer is to go back to the workshop, where we have about a hundred little piles, each representing an aggregation of the atoms of one of the elements. Some of these atoms are large and seem to contain a great many electrons flying about, while others are much smaller and show only a few electrons.

Let us study these ninety-odd atoms to discover what makes one different from all the others. The first thing that suggests itself is to sort them out, to arrange them in a series according to some one characteristic. We note in general that the atoms seem to differ in size and in the number of electrons revolving about the center—with the proper instrument we would find them to differ also in weight. Searching about we soon come upon an atom which has only one single electron. This atom also is very light in weight—in fact we could easily show it to be the lightest of all. We reason that if it has the least possible number of electrons (one) and has the smallest weight, it must in some sense be the simplest of all the atoms. So we place that at the foot of the list, and look among our atoms for one having two electrons. Soon we discover it and place it next to the first atom (which is that of the light, gaseous element hydrogen).

With this start it is a simple matter to continue the sorting out until all the ninety-odd atoms are arranged in a row according to the number of electrons speeding around their centers. We can number them according to their place in the series, and we

Rudolph Lesch.

SVANTE ARRHENIUS (1859-)

Swedish chemist. One of our great contemporary scientists.

can call this figure the *atomic number* of the element in question. If then someone speaks to you of the element with atomic number 89 you know immediately that it has an atom with 89 of these little electrons circling around the central core, and you also know in general that since this number 89 is close to the end of the series, this element must then have a very large weight compared, say, to the element with atomic number 3.

Furthermore it is now clear that the essential difference between any two atoms is the number of electrons contained.

All this about atoms and electrons, unthinkable speeds and astoundingly small sizes, we have discovered in our imaginary laboratory, by methods and instruments which we know to be purely fantastical. But we must be very clear and definite about just where the imagination and the fantasy end. All that has been said about matter being made of exceedingly small atoms, and about these atoms being composed of electrons and central cores and tremendous expanses of empty nothing—all this is true. Scientists are as sure of it as they are that night will follow day. And yet we are bound to confess that no human eye has ever seen a single isolated atom, much less an electron. Modern microscopes can magnify several thousand times, but electrons, atoms, and even the larger molecules which are made up of hundreds of atoms, are all far too small to be seen in this way.

So no man has ever seen an atom—and yet we have said that scientists are as certain as one can be that they really exist!

How could one be quite certain of the existence of a town, for example, that one had never seen? That's easy! Someone who had seen it and who could be believed, might affirm its existence. But in the case of the scientist and the atom we have said that *no one* has ever seen an atom, and so no one person could give the information to another in the same way and enable one to acquire the knowledge thus second-hand.

The truth of the matter is that the *mind* of the scientist has told him of the atoms and electrons and molecules. Let us take a simple example. Suppose a detective—like Sherlock Holmes, for instance—was trying to solve the mystery of who killed the rich banker. Since the case came to his attention only after the crime was committed, he naturally could not have actually *seen* it. And perhaps the murder was done in a lonely forest far from any other human being, so that it was evident that no person except the murderer could have witnessed the crime.

In his investigations he discloses that the banker had a nephew, who proves to be a young man with a bad reputation and who was known to have a hot temper and no conscience. It then comes out that the banker had made a will leaving all his money to the nephew. On looking into the private affairs of the young man the detective finds that he was in great need of money to replace some bonds he had stolen and that he stood in danger of going to jail if he did not get money soon.

It then develops that the nephew was dining with the banker the night of the murder and that he took

him for a drive in the evening. Finally the detective unearths someone who saw the nephew and the uncle driving on the evening of the murder toward the forest where the dead banker was later found; and this same man, it seems, saw the nephew return shortly after alone and in a high state of excitement.

When, later, a pistol is found with the nephew's name on and with one cartridge fired, in the forest —certainly it wouldn't take as clever a detective as Sherlock Holmes to reach the conclusion that the nephew had murdered his uncle. Everybody would believe it and it is safe to say that the young man would be hanged without much hesitation by any jury.

And yet nobody *saw* the murder. The *mind* of the detective gave the answer—not his eyes or anyone else's. He reasoned it out.

As with the detective and the murder, so with the scientist and the atom. Although he has not seen the atom itself, he has seen many other things, and he has *reasoned* that since these other things (of which he is really sure) are true, then what we have said of the atom and the molecules and the electrons must be true.

But man did not get this simple and beautiful picture of the architecture of matter so quickly and so easily as it might appear from this brief story. It took many hundreds of men many hundreds of years of close observation of the things before their eyes before they were clever enough to guess that if matter were made up of atoms these things would be easily explained—just as the detective finally saw that if the nephew had committed the murder

all the facts he discovered would be simply accounted for.

For many centuries past men who study Science had asked themselves a simple question. It was the same question to answer which we constructed our magic workshop and performed our wood-chopping experiments. It was: "If one were able to cut up into successively smaller bits a mass of any *element* (carbon, for example) would he find it possible to continue this operation forever—or would he finally obtain a small bit of carbon which, for some reason, could not be further divided?"

As early as two thousand years ago men were asking themselves this question. Their method was to sit under a shady tree and think about it—much like our dreamer in the garden. Some of these ancient men answered "No" and others answered "Yes." It was largely guesswork, for there was no real reason for answering the question one way or the other. Men had not learned the importance of making experiments to test out their ideas. And so for long centuries the question rested; some thought one way and some another, and hardly any two men agreed.

But as the long years unrolled and men became better thinkers and used more efficient methods, a great many facts about the behavior of matter under various conditions came to be known, and as scientists pondered upon the explanations of the things, it gradually became evident that the solution hinged on the answer to the question we have put above.

This was about one hundred and twenty-five years ago. At this time there lived in England a

minister, named John Dalton, who found pleasure in performing scientific experiments as a sort of hobby —just as one might collect stamps or be a radio "fan."

Dalton was interested in this question about whether matter could be divided indefinitely into bits. But he could not go at the matter directly, as we imagined ourselves doing. It was necessary, since he was dealing with real things, to go a roundabout way. Certain scientists had found ways to analyze compound substances. That is, they could take a material made up of several elements, and discover what these elements were. Starting with sugar, for example, they could show that it contained the three elements carbon, hydrogen and oxygen. It is hardly necessary to add that they did not do this by the simple method of cutting the sugar into small pieces, as we did in our imaginary experiment.

Analyses such as this were made of many substances. When studied over, these experiments brought to light some interesting facts. In the first place, it was found that sugar, for example, not only always contained the same three elements, but also that these three elements were always present in exactly the same relative amounts. In other words, suppose that ten pounds of sugar from Cuba showed a certain number of pounds carbon, so many pounds hydrogen, and so many oxygen. What we just stated, then, means that if ten pounds of sugar from anywhere else in the world were analyzed, it would also contain *exactly* these amounts of carbon, hydrogen, and oxygen. This was found to be true with every

other compound analyzed—the proportion by weight of the elements was always the same.

Another fact was known from this analysis of compounds into their elements. Sometimes two compounds were found to contain the same elements, although the compounds themselves were quite different. For instance, water proved to be made of hydrogen and oxygen. Hydrogen peroxide, the common household germ-killing medicinal, also analysed into the same two elements, hydrogen and oxygen. But it is well known that water and "peroxide" are very different substances. The explanation was found when someone discovered that while, in these two substances, the kind of elements was the same,—yet the relative amounts were not at all the same. Thus in water sixteen pounds of oxygen was found combined with two pounds of hydrogen, and in hydrogen peroxide thirty-two pounds of oxygen with the same amount of hydrogen.

Do we notice anything particular about these figures? Well, John Dalton did, anyway. He observed that 32 is just exactly twice 16. In other words, in hydrogen peroxide, just twice as much oxygen by weight is associated with a certain amount of hydrogen, as in water.

And, as John Dalton found, this wasn't just an accident. He found that the two elements nitrogen and oxygen combine to form as many as five different compounds. When he investigated the relative amounts of oxygen in these five compounds, he found that they could be arranged in a series according to the amount of oxygen they contained to a

certain amount of nitrogen. These amounts by weight of oxygen he found to be 16, 32, 48, 64 and so on, each number being 16 multiplied by 1, 2, 3, 4, and so forth. In no case did he find one of these multipliers to be 1½ or 2¾. They were always whole numbers.

Dalton was puzzling over the fact that these multipliers were always whole numbers. What sort of architecture could matter have to cause such a striking thing? He decided he would pretend that elements were made up of very tiny grains which could not be divided further—he simply "made believe" that this was true and tried to figure out what would happen. And like the small boy who tied a dog and a cat together by the tails, just to see what would happen, he did not have long to wait.

It was clear to him that matter must indeed be made up of atoms and could not be continuously divisible. The fact that the multipliers were whole numbers simply meant that the compound contained so many *whole* atoms. If we had gotten 2½ for a multiplier, that would have meant two and a half atoms. But we never did get half an atom, and consequently, so Dalton reasoned, we *could not have half an atom;* an atom could not be cut in two—one must take a whole one or none at all.

So we see how John Dalton got the idea of atoms entirely by using his head. He couldn't see an atom, but he could see other things, such as the figures from the analyses of compounds of elements, and, like the detective, he simply stretched out his hand and seized the criminal—the sly and elusive little atom which had been causing all the trouble.

In a certain dogmatic sense, Dalton's idea about atoms was a sort of guess. He was not perfectly sure of it. But since that time over a century ago scientists have discovered many other things about matter, and not a single thing has been discovered which would seem to hint that Dalton was wrong. And so to-day, as I have said, scientists are quite as sure of the existence of atoms as if they had actually seen them and handled them in some magic laboratory like ours. Surer, if anything, for they have seen them with that much more trustworthy organ—the eye of the mind.

CHAPTER V

ENERGY AND HOW IT MAKES LIFE INTERESTING

When one gets up in the morning after a sound night's sleep, has a hearty breakfast and goes out into the warm spring sunshine, one feels as if he could conquer the world. We are accustomed to describe such a feeling by saying we are "full of pep." Or, if we wish to avoid slang, we say "full of energy."

We mean by that that we feel able to do an enormous amount of work. But we might also describe a bullet that has just been shot from a gun as being "full of energy." This would be quite correct, and the meaning would be that the bullet in its present state of motion is capable of doing a great deal of work. In the case of ourselves, if it is only our muscles that are full of energy, and if the brain which directs our muscles happens to be lazy, then the chances are our energy will be expended sitting under a tree munching an apple and dreaming, and the work we do won't be worth mentioning.

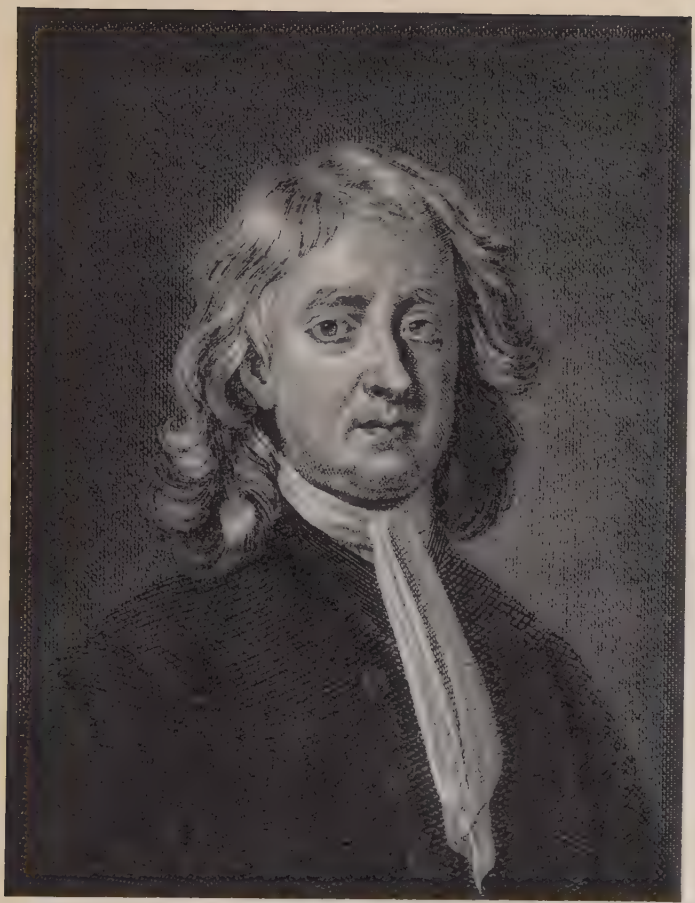
But the bullet is different. It has no mind to whisper, "What's the use of working so hard? Why not stop here on the grass and dream?" It cannot stop unless something stops it. Not only that but it vigorously resents being stopped and works hard to convince the object that stops it of that fact.

For example, if a piece of wood gets in its way, it does its very best to plow right through the wood and thus does work in pushing the molecules of wood apart so it can get through; also it generates heat in the plank, which is work, too.

Years ago there lived a great Englishman named Isaac Newton. Newton had a passion for trying to understand things that were mysteries to other people. One day, so the story goes, Newton was sitting under an apple tree. A little puff of summer wind came and a big, red apple fell and hit him on the top of his head. Newton was getting along in years and there was probably not much hair on the top of his head, and we can well imagine that the falling apple hurt him considerably. You or I, in such a circumstance, would probably have angrily transferred our repose to the shade of some tree whose fruit was less solid and lighter. But Newton was a different sort. He fell to wondering what made the apple fall *down* instead of *up!*

This sounds foolish, perhaps, to us, but the truth is that this incident started Newton on the discovery of the most important knowledge we have of motion and of gravitation. This knowledge underlies the locomotive, the automobile, the airplane, and in fact every form of mechanical device invented in the last century or two, and it helps us understand those invented even before Newton's time.

One of Newton's discoveries is called the Law of Universal Gravitation. One need not be frightened by this phrase. Gravitation became most real to us with our first childhood experience of losing our grip on some object entrusted to our care and having it



Rudolph Lesch.

Sir Isaac Newton (1642-1727)

English mathematician and physicist. Noted for his laws concerning motion and gravitation.

crash, with sad consequences, to the floor. Experience has taught us that any solid body whatever—or any liquid—if it is not held up by the hand or a table or something similar, will fall in the direction of the ground.

We say that this happens "because of gravitation." We are not at all certain of what causes gravitation, and so it is best to consider the word gravitation as simply describing the tendency of things to fall.

Now we understand the meaning of gravitation. Let us consider the significance of the phrase "universal gravitation."

The earth is apparently a roundish ball of matter of great size and weight from our point of view, moving with a considerable speed in a curved path around the sun. But our telescopes show us many millions of other such balls of matter. In fact, one can see many thousands of them by looking into the sky on a starry night, even without a telescope.

These balls of matter are millions of miles apart. We do not know how many there are, nor how far they extend out into space, but it pleases us to imagine that if we traveled out in a straight line from this earth for millions and millions and millions of miles, we might finally reach a place where there were no stars.

If we did that, and if indeed we were able to find the end of the stars, we say we would have reached the end of the "Universe." So by Universe we mean all the matter there is anywhere and the space this matter occupies.

To speak of "universal gravitation," then, means

simply that gravitation acts everywhere in the Universe.

Take for example the case of a stone which is pushed off a cliff. Here we have two bodies, the stone and the earth. One is small and light; the other is very large and very heavy. The tendency is for these two bodies to rush together. This means that either they must both move towards each other, or that one of them moves towards the other. It is plain that it will require a very large force to cause an enormous body like the earth to move. Therefore, the stone moves towards the earth.

So it is with all other objects on our earth, for all of them are of course very small and light in comparison with the earth itself. When unsupported, all bodies on the earth tend to fall towards the earth.

But we said that gravitation was universal. If this is true then we must say that any two stars have a tendency to "fall" towards each other. That is exactly what Newton tells us. Any two bodies in the Universe are urged towards each other, whether these bodies are stars or pins.

But we spoke above of Newton's *Law* of Universal Gravitation. The *law* of gravitation tells us the *amount* of this gravitational attraction between any two bodies. Newton discovered that two things determine this—the distance the bodies are apart, and the amounts of matter in each of the bodies. The closer the two bodies are together the stronger is the pull drawing them still closer together. But the pull decreases very much faster than the separating distance. Thus the attraction when two

bodies are one mile apart is ten thousand times the pull when they are one hundred miles apart. If one of the bodies is very small and the other very large—for example our earth and a man—then the attraction between them would be practically nothing if the man went up a million miles from the earth.

Now it probably has become evident by this time that what we are speaking of as the attraction between the earth and a body near its surface is nothing more nor less than what we ordinarily speak of as *weight*. Reading over the last paragraph with this new idea, one reaches the rather surprising conclusion that a man weighs less the higher up he goes, and if in some way he could rise to a position a million miles from the earth he would weigh practically nothing at all and could float through space with no effort whatever.

The quantities of matter in the two bodies also affect the gravitational attraction between them. Two objects have to be very, very heavy, and exceedingly close together before we can detect any tendency for them to come together. But in our imaginary laboratory where we worked with atoms and molecules, we may also pretend that we can use objects the size of stars and suns for playthings.

Let us perform this experiment. Step up into the sky some fine evening and bring down to our magic workshop an assortment of stars of various weights. Now take one star weighing a million tons and another larger one weighing twenty-five million tons. Place them on our workbench exactly one thousand miles apart. You will find your two stars

showing a tendency to move closer together. Hold them back so that they don't move at all. Note the force it is necessary to use to prevent their moving. Now choose two other stars exactly alike, and each weighing five million tons. Place them the same distance apart, namely, one thousand miles, and again note the force required to prevent them from rushing together.

The force required in each of these two cases will be exactly the same. Now we said that the gravitational attraction depended upon the distance apart and the weights. In the two experiments above the distance apart was the same, and the gravitational attraction was the same. Therefore the weights must be the same. But, you protest immediately, the sum of twenty-five and one is not the same as the sum of five and five. No, but twenty-five *multiplied by* one is the same as five *multiplied by* five. It is not, then, the *sum* of weights of the two bodies which is important in gravitation, but rather their *product.*

All the millions of stars in the Universe are pulled together by gravitation. I will not stop now to answer natural questions about why the stars do not actually fall together. That will come later. Now we must get back to Newton.

Newton also became interested in motion, and reached several very important conclusions. One of them was that every body in the Universe continues moving in a straight line at the *same speed* unless something occurs to stop it or slow it up. Thus, according to Newton, a bullet fired from a gun, with a muzzle velocity, say, of 1000 feet a second, will

continue to speed onward a thousand feet every second—unless something stops it. This may sound rather absurd. Of course we all know that a bullet shot from a gun will eventually fall to the earth even though no object like a house or a man comes in its path to stop it.

The joker in this law of Newton's is in the qualifying phrase "unless something stops it." It is easy to demonstrate that there are two things which operate to slow up and finally to stop the bullet. One is the air through which it moves. Air is matter, and therefore consists of small particles—molecules—moving about. Now the bullet is large and the molecules of air are small and rather close together. It is evident that if the bullet is to get through the air, it must push aside some of these air molecules. This represents work for the bullet, just as the similar operation means work for the football player who is pushing his way through the opposing line.

We have learned that the moving bullet has energy because it is moving, and that the faster it is moving, the more energy it has. If now we consider that it has to do work in pushing aside the air molecules, then we are bound to conclude that it is losing energy all the time. And since it is losing energy, it must be losing motion; that is, it must be slowing up.

The moving bullet loses a further amount of its energy due to gravitation, as we have already learned, because it tends to fall to the ground.

So the bullet loses energy due to the friction of the air and due to the gravitational pull of the

earth. Eventually it must lose all of its energy in this way, and must of course fall or come to rest on the ground.

It may exercise the imagination to consider a bullet fired from a gun somewhere out in space where there is no earth and hence no gravitation, and where there is no air. If we could perform such an experiment we would see that Newton was right. The bullet would continue moving with the same speed forever.

The excellent French writer, Jules Verne, has a story about a party who wished to travel to the moon, and constructed a huge, hollow shell to be fired from a monster gun on the earth. Placing themselves inside the shell, they had the gun fired, and they shot forward with such a speed that they had energy enough to overcome the force of air friction and so managed to travel straight out from the earth about six hundred miles (we are fairly certain that there is practically no air beyond this distance from the earth's surface). Since there was no air, and since the distance from the earth was so great there was no gravitation, the projectile then sped forward with never-changing speed for millions of miles. The plot is intricate and fascinating. There were many amusing incidents. One of the party accidentally dropped a glass of water. To everybody's surprise, it didn't fall and the water didn't spill but remained suspended in space, because there was no gravitation. The dog died and they threw him out of the window. Imagine their discomfort in finding that the dead dog traveled right along beside them on the outside. There was no

gravitation to make him fall and he just continued moving as when he was alive and inside the shell.

All material bodies possess energy of some kind. While there are many varieties of energy (electrical, heat, mechanical, etc.,) we can divide them all into two general classes: Energy of Motion and Energy of Position. You remember we became acquainted with these two kinds of energy in one of the earlier chapters when speaking of the waterfall and the moving baseball. Depending upon *what* the body is, and *how* it is moving, we get one kind of energy or another.

Perhaps the most important thing we know about energy is that it is impossible either to make it out of nothing, or to destroy it. We have considerable control over energy. We can change its form, and we can put new dresses on it. Sometimes we have imagined that by dressing it up differently we have so effectively disguised it that it is no longer energy but something else. But on each such occasion it has turned out that when we looked closely enough at our new "creation," there was our old friend Energy grinning and leering at us from behind some wondrous mask, unchanged and offering ready proofs of his identity.

To say that energy cannot be created is another way of saying that in our everyday world of food and drink and business and commerce we cannot get something for nothing. Magicians who can produce a beautiful princess or a gorgeous castle where nothing stood before, live only in fairy tales. But no less fantastical are the dreams of those who

promise to give us food and drink and light and warmth and transportation—for nothing.

It is not given to the human mind to create, in a literal sense. Like the checker player, our sole activity is moving the pieces—the various kinds of energy and matter—around on our little board which is the earth. If there should come a wicked devil to steal away our playthings, we would quickly realize how weak and unimportant we really are.

So we are chiefly concerned with changing one kind of energy into another. An arrangement which will enable us to do this we call an *engine*. The steam locomotive is a good example. What we want here is mechanical energy in order to turn the wheels and move the engine. What we have is coal and water and oxygen in the air. The coal has a certain amount of energy owing to the arrangement of its molecules and atoms. Water and oxygen also possess considerable of the same kind of energy. When coal and oxygen combine, a third substance, carbon dioxide, is produced, which has less energy, due to its molecular arrangement, than the coal and the oxygen had together. We might picture it in this way:

COAL + OXYGEN GIVES CARBON DIOXIDE + ENERGY

If we bring about this combination of coal with oxygen, then, this excess energy is made available. That is, it appears as heat (and some light). The combination of coal (or wood, or similar substances) with oxygen is of course what is termed burning; everyone is familiar with the heat given out when things burn.

In the steam locomotive we burn coal, and

change the energy possessed by the molecules and atoms partly into heat energy. This heat energy we use to convert the water into steam. Now steam is a gas, and, as we learned in an earlier chapter, has a tendency to occupy a very large volume compared to the water from which it came. In our boiler the space for the steam is limited, and so this gas is forced by the boiling water into a space much smaller than is consistent with this expansive tendency. It consequently presses against the sides of the steam chest with considerable force, and sometimes engines have been blown up by allowing the steam pressure to reach too high a value. In our locomotive this compressed steam is admitted into a steel cylinder in which a close-fitting piston works back and forth. This piston is so connected with the wheels that if the piston moves through the cylinder, the wheels turn around. The inrushing steam pushes the piston down, the wheels turn, and so on.

In the case of the locomotive we convert heat first into energy of motion of the steam molecules, and then this in turn into energy of motion of the piston and the wheels.

Most of our engines start in this way with heat, obtained from things burning. This is because things that will burn, like coal and wood and natural gas, are very plentiful on the earth. Although we usually start with heat energy, we do not by any means always end up with mechanical energy. In a certain kind of engine for producing electricity, for example, we use an arrangement exactly like the steam locomotive, except that the piston, instead of turning the wheels that move the engine along a

track, turns a wheel that rotates between powerful magnets. Energy of mechanical motion is thus changed into electricity (or more properly, electrical energy).

It is rather interesting to speculate on a world where things that burn are very scarce, but electricity, say, is quite plentiful. In such a world, doubtless, electric lights and telephones would have been in common use long before man learned how to build a fire.

The principle, stated on a previous page, of the impossibility of creating energy has not been known a very long time. The first suggestion came when Count Rumford, observing the boring of cannon at an arsenal in Germany, noticed that the heat developed in the boring was just about doubled when the mechanical energy expended was doubled.

Later Joule, an English beer-maker who carried out delicate scientific research with only the implements to be found in a brewery, arranged a clever experiment by which he showed that when mechanical energy is changed into heat (as by a falling weight turning a paddle-wheel in a pail of water, so that the water gets hot) the amount of heat for a given amount of mechanical energy is always the same, even with entirely different machines, and that if we halve the mechanical energy used, or double it, or quarter it, or, in fact, do anything we like to it, an exactly corresponding change is produced in the amount of heat developed in the experiment.

This showed that as far as two kinds of energy were concerned, one was completely transformed into the other without the slightest loss or gain. In

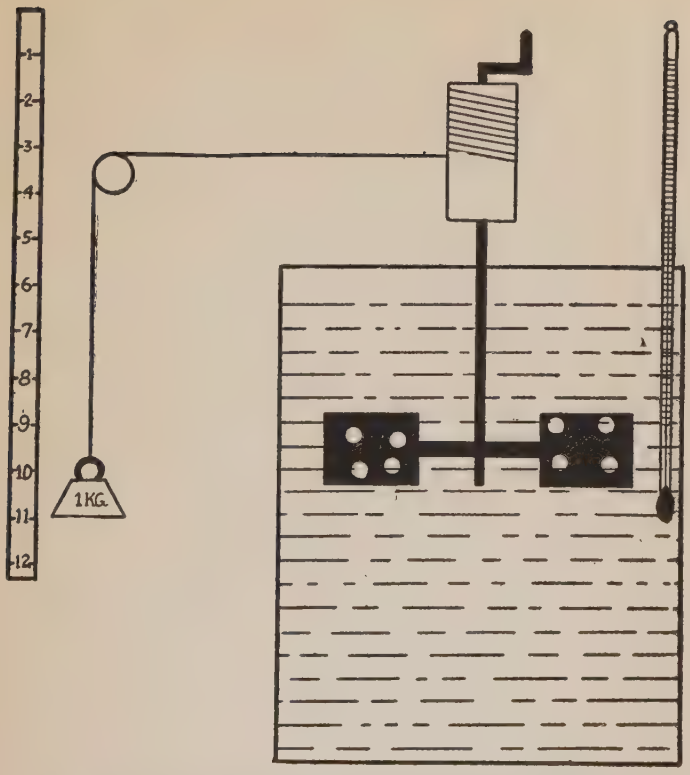


FIG. 2.—Joule's Experiment on the Mechanical Equivalent of Heat. The weight, falling through a measured distance, does mechanical work by turning the paddle-wheel in the vessel of water; the agitation raises the temperature of the water. The product of the quantity of water by the number of degrees rise in temperature equals the quantity of heat energy added (in calories), and this is equivalent to the mechanical energy expended by the falling weight, which in turn is measured by the distance it falls times its weight.

other words, starting with a given amount of mechanical energy and changing it completely into heat, we always obtain just so much heat, no more and no less.

This has been proven for all the other kinds of energy, as far as it is possible to prove anything. That is, we have never studied a case where energy appeared to spring from nothing, or to vanish into thin air. Sometimes it looks as if we have a case that violates the principle of the indestructibility of energy. For example, we perform an experiment in energy change, measuring the amount of energy we start with, and the amounts we end up with. It has happened that the total energy at the finish appeared to be less than that at the beginning. In every such case so far we have gotten around the difficulty by saying that here we have a new kind of energy which we didn't include in our summing up because we didn't know about it before. This may sound a little like shaping the head to fit the hat, but, as a matter of fact, whenever we have invented a new form of energy in this way, we have been able later to prove beyond doubt that this form really exists. Of course, somebody may bring forward a case to-morrow which we can't get out of so easily, but the chances are pretty good that they won't.

Besides these engines which change one kind of energy into another kind we happen to want, we have also devices called *machines,* which do not change the kind of energy but rather make it easier for us to use a single kind.

One of the simplest machines is something like a seesaw. In the seesaw you have a long plank

balanced at its center on some sort of support. Let us see how we could use the idea of this plaything in a practical way. Suppose that in some way an immense stone has fallen on your hat. You must have your hat, and the stone is far too heavy for you to lift in the ordinary manner.

Get a long plank and a small stone. Place the small stone near the large one and let the plank act as the plank in the seesaw. Let it rest, close to one end, on the smaller stone (which corresponds to the support in the seesaw) and stick this end as far as possible under the large stone you want to move. Now if you place yourself at the other end of the plank, you are ready for action. The difference between the seesaw and the machine you have made is that the support is not at the center of the plank but very close to one end—and to that end indeed where the heavier stone rests. Instead of yourself and another body on the seesaw, you have yourself and the stone. The idea is that by pulling down on your end of the plank you will raise the stone into the air, just as in the seesaw you raise your partner up when you go down.

You will find, if you actually try it out, that you are able to raise in this way a stone many times too heavy for you even to budge in the ordinary manner. Why is it?

Well, why is it hard to lift a stone, anyway? The answer is easy. When one tries to lift something, he is simply pitting his muscular strength against the earth. Or, in other words, he is fighting against gravitation. Obviously, then, to raise a body weighing so many pounds a certain distance above

the ground, one has to do a certain amount of work with his muscles. It will also be plain that the work done remains the same whether he lifts it with his hands, uses the seesaw method, or pays somebody else to do it.

How, then can our seesaw enable us to do the work when we cannot do it with our bare hands? It is simply that the seesaw allows us to spread out the work over a longer distance. Suppose we wish to raise the stone one foot above the ground. If you are interested in the practical side of it, go into the yard and set up a model of our experiment, using two stones and a stick. Or if you don't care to go out, use a coin and two matches. Notice how everything looks before you begin the lifting. Your end of the stick is high in the air, the other end rests on the ground under the stone (or the coin). When the stone goes up one foot, that end of the stick must also go up one foot. You will see that while that end of the stick moves upwards a distance of one foot, your end on which you are pulling must go down several times one foot. Try it and see.

There we have the answer to our question. The seesaw simply allows us to do the work we have to do in small steps, so that the force with which we have to push the stick at any moment does not exceed our strength.

The principle is the same as that of saving money. For example, suppose a boy is earning three dollars a day, and every night he puts aside five cents. Of course he will hardly miss the five cents. At the end of the month he has $1.50 in his savings. Suppose, on the other hand, that instead of putting aside

five cents every day he waited until the last day of the month and took the whole $1.50 out of his salary for that day. Of course it would hurt much worse to do it this way, and so in saving money we commonly adopt the former method of a little at a time.

This seesaw method (it is properly called the

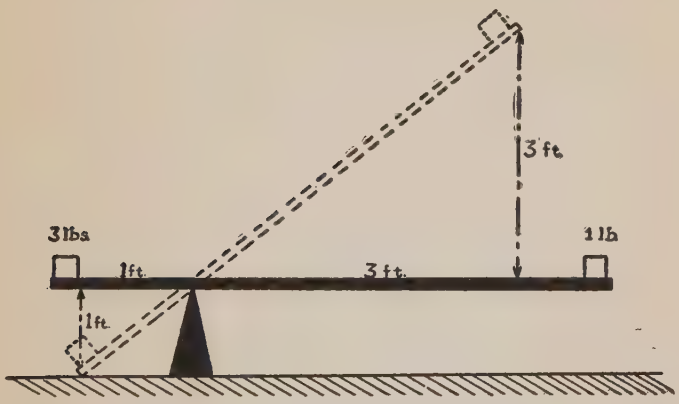


FIG. 3.—The Principle of the Lever. The lever is balanced when the product of each weight by its distance from the point of suspension is the same. But note that if one were using the lever to raise a 3-lb. weight from the ground (see broken line) by exerting a pulling force of one pound on the other end, one would have to move his end of the lever down three feet in order to raise the weight one foot.

lever) is a wonderful thing. If we have a very heavy object to lift, we make the plank very long, and place the support very close to the heavy body. That means that we have to move our end of the stick a very long distance to effect a small rise of the heavy object. It looks as if we could move any object whatever, no matter what its weight, if we

have a stick long enough and are willing to pull on one end of it for a long enough time. Such considerations led an ancient Greek, Archimedes, to suggest that if someone would give him a very, very long stick, a support to rest it on, and a place to stand, he could move the world itself! The stick would have to be many times as long as the earth is thick, and the support would have to be, perhaps, another planet heavier than the earth, and the operator would have to work at the far end of the stick thousands of miles out in space, but if these few practical difficulties could be overcome, the feat would doubtless be possible.

There are many different types of machines, but the principle is always the same, changing the *rate* at which we use energy.

Of all the various kinds of energy we know, heat is the one which is the most important, and most abundant in the world. We may say that there are two reasons for this fact. First, we must consider what is called friction. When we change one form of energy into another by means of engines, or when we operate on a single kind of energy with machines, there always occurs a loss of energy. This is because machines and engines are made up of material bodies which move over or through one another or otherwise come into intimate contact.

At the surface of contact between two such bodies, for example, between two pieces of wood, it appears that the molecules of which the wood is composed interlock in some way so that when we slide one piece of wood over the other, part of the force we use acts to break up this interlock. The energy

Rudolph Lesch.

LORD KELVIN (1824-1907)

English engineer and mathematician. Supervised laying of first submarine cable.

required for this sets these molecules into more rapid to and fro motion, which means that the surface of the wood gets hotter. We call the resistance experienced in moving two bodies over each other, "friction." It represents a loss in most cases because we are not trying to heat the bodies but to move them. In the Indian method of rubbing two sticks together to produce fire, heat is what we want, and friction is in this case valuable.

Friction is everywhere. Wherever there is matter and wherever this matter is moving, there must be friction. The rougher the surfaces, the greater the friction. By polishing two surfaces (of glass, for instance) very highly, we can reduce the friction between them to a very low value, but we can never eliminate it entirely.

If friction did not exist, the world would be a sorry place. You know how difficult it is to walk on slick ice. Imagine what would happen if you had to walk on a surface infinitely smoother than ice. You couldn't do it. The slightest motion in one direction would send you off in that direction and you could never stop. The brakes on automobiles and trains, etc., all depend on friction for their operation. In many cases we strive to reduce the friction to the lowest possible value. In others we want all the friction we can get. In the automobile we use oil in the motor and around all moving parts to reduce friction (the oil seems to fill up the irregularities in the metal surface and make it smoother), and yet the brakes work by pressing a lining of asbestos against the metal of the axle, producing great friction. We couldn't live without

friction and yet engineers and others are doing their best to reduce it.

As stated above, the energy used up by friction takes the form of heat. The full significance of this is very important. Energy of any kind has a tendency to make things move. When the body moves a part of the energy is always lost as friction. Friction means heat. This suggests that all kinds of energy are slowly changing into heat. That appears to be the case. We do not know why this is.

If you place a hot brick in a cold room, it rapidly loses heat and eventually becomes of the same temperature as the room. Hot bodies lose heat principally by actual contact with other bodies which are colder. The tendency is for heat to distribute itself uniformly everywhere. The molecules of air around the hot brick absorb some of its heat and move faster. They strike a chair or a wall and thus communicate some of their heat to these objects. The process goes on until everything in the room is at the same temperature.

This characteristic of heat energy to distribute itself in all directions, together with the fact that all other forms of energy, when associated with matter, lose a little of their substance as heat, accounts for the great abundance of heat, and shows why it is so important to the world.

CHAPTER VI

HEAT AND THE DANCE OF THE ATOMS

We saw in the last chapter how the amount of heat a substance contains determines whether it is solid, liquid, or gaseous. Heat is a very important part of our daily life. In winter time we go to lots of trouble and expense to produce heat to keep us warm, and in summer time we drink ice-water to get rid of it. Nature seems never to provide exactly the right amount to satisfy us.

Several million years ago the first creatures who were more man than animal made their appearance on the earth. In connection with heat it is interesting to mention that almost the first activities of these early men had to do with fire.

Animals who lived in cold climates were provided by Nature with warm fur, but the bodies of men were not so protected and so it was natural that they should become interested in the warming qualities of fire. Perhaps a lightning storm had set fire to a forest and the primitive men had noticed with pleasure the heat produced by the roaring flames. It was not long until someone discovered that brush and other things could be set on fire by rubbing two dry sticks together. Sometime later a better method was devised in the production of sparks when two

pieces of hard stone such as flint were struck together in a certain manner. Thus fire-making was one of the first things that mankind learned to do and it is something that no animal can do to this day.

For a long, long time fire continued to be made by the method of striking pieces of flint together. Only about a century ago were matches introduced. A Frenchman noticed that the element phosphorus (a soft, white solid) had the peculiarity of bursting into flame when rubbed violently—that is, when subjected to friction. So he coated little sticks of wood with the phosphorus and some other materials and thus made the first match. These original matches attracted much attention, but only as curiosities. They were sold on the streets of London like toy balloons are sold nowadays, and country-people returning home from a visit to the city with one of these queer fire-sticks were certain of amusing their friends for a whole evening.

This first match was a clumsy affair, and was dangerous to handle because phosphorus is very poisonous when put into the mouth. Some years later two Swedish scientists found that the poisonous, waxy phosphorus, if subjected to a simple treatment, could be changed into a red powder which was not poisonous at all and which would not take fire unless struck against certain things. They made matches of this red phosphorus and put them in boxes on the sides of which was some material on which the matches would strike. These were the first "safety matches" and as you know are used by almost everybody to-day. These safety matches are

manufactured almost entirely in Sweden where the yearly output of the little boxes of matches, if placed end to end, would reach several times from here to the moon and back!

It is natural for us to ask what causes the phosphorus to catch fire. And the answer brings up a very interesting matter about love-affairs among the chemical elements, of which phosphorus is one. The air about the earth is about one-fifth oxygen, which, you recall, is one of the gaseous elements. Now Oxygen is a very wicked individual. He is the Bluebeard of the elements. But, unlike Bluebeard, he is evidently a young man of very pleasing appearance and manner. His weakness is falling in love with the other elements, and he seems to have an almost irresistible attraction for most of them. Wherever he is you will find the other elements crowding around, fighting with each other for his favor. He lures them on with fine promises of castles in the air. But when one of the poor, misguided little elements touches the hand Oxygen so gracefully extends—in a flash all is lost. Oxygen seizes her in his iron grip and henceforth she is his slave. She is no longer a simple, care-free element. She is firmly bound to Oxygen and usually must remain so. In most cases the brave little element puts up a fight that compels our admiration. Unwilling to give in without a struggle, she kicks and screams and in other ways expends a great amount of energy. And all that we men who are watching this little tragedy usually see is the result of the kicks and yells of the little element. It appears to us in the form of heat.

The elements differ considerably among themselves in the ease with which they allow Oxygen to lure them on to ruin. There are three or four of them in fact who might be called Old Maids, for they never have been known to strike up a friendship with Oxygen or with any other element. But Phosphorus is at the other extreme. She seems quite unable to resist the charms of Oxygen if he is anywhere around. The moment, however, that Oxygen grasps her hand in his death grip, she seems to wake up to the frightful situation her flirting has got her into. She screams and yells and kicks as no other element could and creates such an awful "rumpus" in fact that all we, who are looking on, can see is a burst of flame. But all her struggles are in vain, for when the flames die away we see a dull white powder floating gently in the air—all that is left of the formerly lustrous and active little element.

The white powder is composed of phosphorus and oxygen and is called phosphorus oxide. To the element Phosphorus and to the other elements which fall into Oxygen's clutches, it represents the tragic end of their individual existence and the beginning of an eternity of hateful slavery. But Man has learned to recognize in the combination of elements with oxygen a process of tremendous importance to his personal comfort, to the cooking of his food, and to the carrying on of his manufacturing operations. The strange change of heart which the elements experience, once they feel themselves actually in Oxygen's grasp, and the great fuss they invariably kick up, means to Man simply that a great amount

of heat is developed when things enter into combination with oxygen.

We see then that heat is produced in the match by the union of the phosphorus on the match-head with the oxygen of the air. Two other points regarding the action of the match now occur to us. First, why is it necessary to rub the phosphorus against something in order to make it combine with oxygen and produce heat? And second, what is the connection between the heat so produced and the *flame* we see on striking a match? . . . Let us consider these questions one at a time.

We have seen in a previous chapter how atoms are composed of particles which are moving in circles with incredible speeds. If we look at a piece of stone lying motionless on the ground, it requires some little imagination for us to think of its being made up of billions of little atoms which are almost literally points of violent motion. A still greater shock to the imagination will be caused by what we shall now describe.

The various atoms of the stone are united to form molecules, as we have learned, and these molecules are themselves of exceedingly small size and are infinitely numerous in even a small piece of stone. Scientists believe that these molecules are also, like the atoms which compose them, in motion. The motion is not so fast as with the electrons, but yet faster than our speediest airplanes. Furthermore this molecular motion is not around in a circle, but is a to-and-fro movement something like the motion of a swing or of the pendulum on a clock. In solids like stone it would appear that the molecules

are not able to move very far away from their middle position, but rather vibrate backwards and forwards about this middle position somewhat as a knot made in a violin string will do if the string is plucked.

We believe this to be true not only of stone and other solids, but of all kinds of matter in general. In liquids the motion of the molecules is not confined so strictly to one little groove or track, but they may dart about almost as they like anywhere within the body of the liquid. In gases there is a further relaxation of the rules and regulations, and the molecules go where they please and are apparently anxious to get as far away from each other as possible. It requires not much thought to see how all this about the motion of the molecules in solids, liquids, and gases, accounts in a simple manner for the characteristics by which we distinguish these three states of matter.

This molecular motion is closely bound up with the heat which a body contains. In fact molecular motion is the way a body stores up heat that it receives. It is a sort of savings bank for heat. If we heat the stone in the fire, we consider that the rapidity of vibration of its molecules is increased. When the stone is removed from the fire, and gradually cools off, we believe that this corresponds to a gradual decrease in the speed at which its molecules are moving back and forth. This loss in speed is transferred to the molecules of the air around the stone, and this means, of course, that the air becomes hotter. Most of the energy lost in heat by the stone is gained by the surrounding air; what is left over

is used in making small amounts of other kinds of energy. At any rate we know that none is lost—it merely changes its form.

Now friction—rubbing solids together—as we learned in the last chapter, always makes itself felt by the production of heat in the bodies which are rubbed together. This is a simple example of the transformation of one kind of energy into another. We effect the rubbing, which in turn produces the friction, by means of the muscles of our hands. We do a certain amount of work and this work largely appears as heat in the objects we are forcing over one another. What actually happens in striking a match is that the energy of motion produced by our muscles is transferred to the molecules of phosphorus on the head of the match. These molecules vibrate faster and the match gets hotter.

Let us now examine with our magic microscope the head of a match. We see that the molecules are vibrating with a certain speed. If the match is in air, we can also see the molecules of oxygen flying about. Once in a while a molecule of oxygen happens to get very close to one of phosphorus. There is a tiny flash and a grain of white powder—phosphorus oxide—results. Now let us draw the match head along the surface of the box, still observing with our microscope. First we notice that the molecules of phosphorus and those of oxygen in the air about begin to move faster; the phosphorus molecules have a longer swing, and they get farther away from their middle position with each successive vibration. As we look we observe something that common sense might have told us. With this

increased motion, the number of times in a second that a phosphorus molecule meets an oxygen molecule becomes greater. With each meeting there is a little flash and heat is developed. The current of colder air moving about the match-head carries part of this heat away, but as the meetings and the flashes become more frequent, the air becomes unable to dispose of all of the heat developed. The consequence is that the heat remains and adds itself to that produced by the friction, serving to increase the molecular motion still further.

Following this amazing business still further, we see that the match-head becomes hotter and hotter as the encounters between the opposing molecules of phosphorus and oxygen become more and more frequent. There comes a time very soon when the heat at the very tip of the match from these causes becomes so intense that the whole match-head bursts into flame. This flame of course sets fire to the wood of the match stick.

But why does the match burst into *flame?* What has the flame to do with it, anyway?

A flame consists of small particles of a gas or of a solid which give out light. Now light, like heat and mechanical motion, is a kind of energy. That is, work must be done to produce light. Light is invariably associated with heat. In other words, anything which gives out light, must also be hot. In fact it must become hot *before* it gives out light. That is a fact familiar to everyone. Our chief artificial sources of light are electric lamps and fires from anything that is burning, such as wood, or candle tallow or coal. Everyone knows that all fires

are hot, and it is a fact easily verified that heat is developed in the electric lamp. The world's greatest source of light—the sun—is also known to be intensely hot.

The relation of light to heat is best seen by consideration of the vibration of the molecules which compose the substance being heated. Let us again go to our imaginary microscope and observe more closely what happens to the molecules of phosphorus and oxygen as they become hotter. We saw on a previous page how the friction started a process which, like a ball pushed over the edge of a precipice, was able to continue in action, gathering speed as it went. The molecules vibrate faster and faster until we can no longer follow their motions. But there must be a limit to this. Otherwise the head of a match, on being struck, would continue to become hotter until the end of the world. The limit is reached when the substance apparently has developed all the heat it can comfortably contain. If more molecules of oxygen and phosphorus remain to combine and produce more energy, then this additional energy takes the form of light. This limit is reached very quickly in the case of the match, and so on striking one of these useful little articles, we are not sensible to a slow rise in temperature up to this point where light is given out—this "kindling point" as it is called—but commonly imagine that the flame appears immediately. What actually happens is that the phosphorus first melts to a liquid, and then just before "bursting into flame" becomes a gas. The flame is due to the light that is sent out by these little molecules of gaseous phosphorus

floating in the air around the match, as they combine with oxygen.

It appears, then, that an object sends out light as an expression of rebellion when more energy is furnished to it than it can conveniently dispose of as heat. A man, if placed in a room which becomes hotter and hotter, would finally begin to cry out with pain when the heat became more than he could bear. The emission of light by a particle of gaseous phosphorus as it unites with oxygen corresponds with the man's cries, and simply means that it had become as hot from the heat produced by the previous combinations of its less fortunate companions with oxygen, as it comfortably can endure—and the small additional bit of heat produced by its own combination is the "straw that breaks the camel's back." There is no more room for heat, and so it sends out its energy as light. A great number of atoms doing this at about the same time, produces what we call a flame.

We said earlier in this chapter that the molecules of all substances, whether solid, liquid, or gaseous, were in motion, and further that this molecular motion was caused by the heat which these bodies contained. More heat, more motion; less heat, less motion. Now this gives us an idea for some more questions and experiments. Up to now we have been talking about adding heat to substances and making them hotter and causing their molecules to move faster. Let us now consider what would happen if we should carry out the opposite process, that is, if we should take heat away from a body.

Now, it is evident that there is some sort of close

relation between heat and cold. This relation is very simple indeed. Cold is simply absence of heat. Whether a given thing is spoken of as hot or cold depends entirely upon who is doing the speaking and how he is feeling at the time. An Eskimo would think a New York winter a suitable occasion for a Palm Beach suit. And a dusky native of Central Africa would doubtless consider a July day in New Orleans as calling for the heaviest overcoat obtainable.

So to avoid difficulties of this kind when speaking scientifically of heat and cold, it has been found necessary to agree upon a standard temperature which can be reproduced by anyone anywhere in the world, and to which all other temperatures can be compared. Such standard temperatures are those at which water boils or freezes. These two temperatures are the same whether the experiment is done in Spitzenberg or Buenos Aires, and since pure water is easy to obtain everywhere, they make convenient reference temperatures. One divides the difference in temperature between boiling water and melting ice into 100 equal parts, each called a degree, and thermometers are simply instruments for registering the temperature of the point where the bulb is placed, in degrees of this scale.

If we reduce the temperature of a body, then, we simply take away heat, and reduce the speed of vibration of its molecules. The question immediately arises: "Is it possible to take away *all* the heat that a body contains, and consequently cause its molecules to become motionless?"

While it is true that this never has been done, we

have, nevertheless, very excellent reasons for believing that it is possible and it will some day become practicable. Within recent years some very low temperatures have been obtained. The method is to change a gas into its liquid by compressing and cooling it. The commonest gas we know of—air—may in this way be liquefied, and great plants are now in operation for making liquid air which is used in the industries for a variety of purposes. Liquid air is an almost colorless liquid very much like water in appearance, but it is so intensely cold that an egg dipped in it becomes frozen harder than a baseball, and quicksilver becomes hard enough to be used for driving nails.

Still colder liquids than this may, however, be obtained by treating oxygen, hydrogen, or the gas helium—which is used for filling balloons—by the same process of compression and cooling. From studies on these liquefied gases and on the gases themselves we are very sure of the exact value of the lowest possible temperature that can ever be obtained. This temperature is 273 degrees below zero (zero is the temperature of melting ice). That means that we must take away from ice-water nearly three times as much heat as we have to add to it to make boiling water, before we have removed all its heat and the hard-working water molecules are given a chance to be absolutely quiet. Liquid helium has a temperature of 272 below, but we have no way at present of going below that. So at present it is impossible to say what things would look like at the absolute zero of temperature—minus 273.

The moral of this tale is: Some day in the dead

of winter when you are so cold that your very bones seem frozen and you remark to yourself through your chattering teeth that it just couldn't get any colder than this—at such a time as this, think of this chapter on heat and cold, look at a thermometer which probably reads about 30 below, and try to imagine how a little molecule feels swimming around in liquid helium, at a mere 272 below!

CHAPTER VII

MAKING SILENCE FROM SOUND

The sense of hearing is one of the important links which connect us to the world. The world is full of beautiful things to hear. There is stirring music to be found in every voice, whether it be the voice of a friend, or the deep-throated roar of some wild animal. Shakespeare spoke of "books in running brooks," and there are few sweeter sounds than a soft wind gently rustling through a forest.

But curiosity cannot fail to impel us to inquire into the nature of hearing. We cannot get around it by simply stating that hearing is what results from the action of sounds upon the ear. What is the ear like, that it alone of all parts of the body enables us to hear sounds?

Before we can understand the action of the ear, we must know what a sound is. Let us repair once more to our magic laboratory and do a little experiment. Attach to one end of a piece of cord some heavy object like a small stone, and tie the other end of the cord to a nail in the wall. Now, taking hold of the free end of the cord with the weight on it, pull it out to one side and then let it go. Everyone is familiar with what happens. The cord swings about as far to the other side as you had

pulled it to your side before releasing it. It seems to remain stationary there for ever so short an instant, then swings back to your side. And so it repeats this performance over and over again, swinging a little shorter distance to each side every time until finally it comes to rest. We are already familiar with this vibrating motion from the discussion of heat.

Now let us take, instead of the cord and the stone, a thin, stiff strip of some metal. Holding one end of the strip tightly in your hand, pull the other, free, end to one side and let it go. Exactly the same thing happens. The strip of metal vibrates swiftly—the eyes may not be able to follow it, in fact—and if everything is just right you may be able to hear a faint sound that accompanies the vibration and seems to come from the direction of the vibrating strip.

That is how sound is produced—by anything vibrating. Let us now see how it reaches the ear, and what it does to the ear to give us the sensation of sound.

Molecules of the gases of the air surround everything. We may imagine our metal strip to be so small that it strikes only one air molecule when it moves. Suppose the strip moves towards the left. It strikes a gas molecule and gives it a push towards the left. Then, because the strip is vibrating, it starts back towards the right. But the air molecule has received its push and it moves towards the left until it hits something. This something is usually another gas molecule. This second molecule receives the push and then moves to the left, while

the first molecule rebounds towards the right. Thus a whole row of gas molecules moves towards the left and then comes back towards the right.

In other words, the row of molecules begins vibrating. Not only that, but, since the vibrating strip causes the air to vibrate, the molecules must vibrate the same number of times a second as the strip.

It is easy to see, now, that if at the other end of the row of vibrating molecules there happens to be another metal strip—or anything else that can vibrate—this object will receive the pushes from the air molecules and will itself start vibrating at the same rate as the original metal strip.

This experiment we imagined ourselves doing with a metal strip the size of a molecule, but it will readily be seen that the same thing will happen no matter how large we make the strip.

We see, then, that sound is sent out from a vibrating body usually through the air. Of course if the space were empty of air and of all other matter, the sound could not pass. This could be shown by placing an electric bell in a vessel from which the air could be pumped. On "ringing" the bell under such conditions, we hear no sound whatever.

The number of times an object vibrates in a second has a great deal to do with the kind of sound it makes. This determines whether the sound is a shrill, high-pitched whistle, or a rasping buzz.

If any object is set into vibration at different speeds, one particular speed can be found at which it will vibrate most vigorously. This vibration

speed which the object prefers above all others is called its *natural period,* and depends on the material of which the body is made and on its size and shape.

We have the same thing among human beings. Not long ago I was introduced to a man at a party. This man and I happened to be sitting together at dinner, and I tried for a long time to make conversation with him. He appeared to be very shy and afraid to talk, and I tried one subject after another without awakening the slightest response in him. He always met my remarks with a polite "yes" or "no" but didn't seem disposed to carry on the conversation. After an hour of this, when I was beginning to despair of ever making this man talk, I happened to mention something about radio. In an instant his face lighted up. "Oh, so you are a radio fan, too!" he beamed, and then *he* talked about radio without a break for the rest of the evening. It was with considerable difficulty that I was able to dissuade him from dragging me to his home then and there to show me his new hook-up.

So this man evidently had a "natural vibration period" in the subject of radio, to which he responded with great vigor, when nothing else affected him at all.

Suppose you have two strips of metal exactly alike and placed some distance apart. Set one of them into vibration at its "natural" rate. We saw previously how the air molecules all around this strip will move back and forth at the same rate as the strip is vibrating. Now some of these vibrating air molecules will strike the second strip and will

have a tendency to make this strip move back and forth, that is to vibrate, at the same rate. Since we said that the two strips were exactly alike, it follows that the second strip will be set into vibration at its natural rate—that rate at which a small force, such as that exerted by the air molecules, is sufficient to make it vibrate almost as violently as the first strip. If we do such an experiment in our imaginary laboratory, it looks quite simple because we see the air molecules pushing on the second strip and making it vibrate. But if we do it in our ordinary world where air molecules are quite invisible, it looks rather like a magician's trick. It is like twin brothers I used to know. If Bill stubbed his toe or cut his finger, not only would Bill start to yell, but also Frank would begin to cry quite as loudly and feelingly, although he was entirely unharmed.

But in the case of the metal strips, if we want such an experiment to succeed, it is essential that the second strip have exactly the same natural period as the first. If it is a little off it will respond only slightly.

Also remember that the two objects do not have to be the same kind of things; only their natural periods must be the same. One might be a metal strip and the other a violin string or a column of air in an organ pipe. One might be a metal strip and the other anything whatever, even a house, as long as their natural periods are the same.

This leads to something truly surprising. Suppose in some way we could find out exactly the natural vibration period of some large structure,

such as the Woolworth Building in New York. Now let us construct a violin of ordinary size, but with a string of such shape and material that it has precisely the vibration period of the Woolworth Building.

Now let us stand with our violin somewhere near the Woolworth Building, and carefully draw the bow over the string. Quite plainly, from what we have said above, the Woolworth Building will start swaying back and forth at its natural period—not very much, of course—but probably enough to send the entire structure crashing to the earth!

No evil individual has succeeded in doing this, simply because there is no practicable way of finding out the natural vibration period of the Woolworth Building.

Now the human ear consists essentially of a thin membrane we call the ear drum which is stretched tight all around and works like the drum in the brass band. This ear drum has not only one natural period of vibration but a great many. In fact it responds to vibrations anywhere from about 16 a second to as high as 32,000 a second. This is effected by changing the shape and tightness of the ear drum by means of muscles. So if there is an object anywhere around which is vibrating at a rate between these two figures, the ear drum will also vibrate at this rate. This ear drum is connected by a complicated nervous system to the brain. Therefore when the ear drum moves a message is sent to the brain saying, "Something is happening in the ear." There is a particular kind of message for every vibration rate from 16 to 32,000. When

we get such a message we say we hear a sound, and that's all there is to it.

If the vibration rate is slow, that is from 16 to 50, we call the sound a buzz. If the rate is high we call it a whistle; and the higher the vibration rate of the whistle, the *shriller* the whistle. You can make a very shrill whistle with your lips, whose vibration rate is near 32,000. Whistle a note, and then another a little higher, that is, a little shriller. If you keep on doing this you will come to a point where the air is passing through your lips, and it seems that you are whistling, and yet you can't hear a sound. Why is this? It is simply that the air in your throat is vibrating at a rate higher than 32,000 and consequently the ear drum does not respond, no message is sent to the brain, and you don't "hear" anything.

A great many animals, insects, and other creatures, have ears, but their ear drums probably respond to different vibrations than ours. The whistle which is so high that you cannot hear it, would probably sound like the roar of cannon to some insects. You've noticed that when you want to call a dog you whistle shrilly, or if you wish to speak to him you use a "high-pitched," that is a high vibration rate, voice. We do it by instinct, but the reason for our instinct is that animals like dogs have ears that respond better to sounds of high vibration rate than of low.

People also talk to babies that way. But it is for no such reason, because babies' ears are certainly not like dogs'. The true reason for baby talk has yet to be discovered.

Rudolph Lesch.

HERMANN VON HELMHOLTZ (1821-1894)

German man of science. Made extensive study of senses of sight and hearing, from viewpoints both of physiologist and physicist. His *Physiological Optics* and *The Sensation of Tone* are classic works in optics and acoustics, respectively. He was the first to analyze complex sounds into their simple components by his system of resonators. He was the grandfather of radio, in that it was at his instigation that Hertz took up the study that led to the discovery of radio waves.

No two people are exactly alike, and the figures for the vibration range to which the human ear is sensitive cannot be exact for every individual. Once in a while there is someone who can hear "sounds" whose vibration rates are somewhat above 32,000 or a little below 16. If two such people should get together, it would be possible for them to communicate without anyone else hearing them.

Silence is absence of sound, and sound, as we have learned, is vibration. So silence is absence of vibration. How then can we start out with two things vibrating and put them together in such a way as to kill that vibration?

Stated that way, the problem doesn't sound so impossible. If two men are running towards each other at exactly the same speed, when they meet both will stop, and out of the two motions you have got no motion. But the neutralization of one sound by another to produce silence may take place and usually does take place in a very different manner. In order to make this clear we must understand exactly what is meant by sound *waves*.

The waves with which we are most familiar are water waves. It is very easy to make serious errors regarding the nature of water waves. First of all, let us clearly understand that a wave running along the surface of a body of water does not move water from one place to another; the thing that is transported is energy. The water wave, then, is a machine, because it receives the energy of the wind, transports it through a certain distance, and then enables it to be expended in changing the shape of a beach or in wearing away rocks, things that the wind

could not directly do. Although a molecule anywhere along a train of waves is not moved in the direction of the waves, it nevertheless executes a sort of motion. It vibrates up and down, at one moment at the bottom or in the trough of the wave that is passing, and at another moment at the crest of the wave which follows. Thus like a cork the little molecule bobs up and down and back and forth, but it doesn't get anywhere.

The motion of such a water molecule in a wave we describe as *periodic*. By this we mean that the particle executing periodic motion does the same thing over and over again. It goes to the top of the waves and then it sinks again towards the bottom; and, having got there, without hesitation it starts back up towards the crest. A single molecule of water in a wave repeats this performance continuously; but it is the combination of a whole row of molecules each vibrating periodically that produces the wave.

Now a sound wave is invisible. The question is, would a sound wave look like a water wave if we could see it? We cannot answer this question with certainty, but the probability is that a sound wave in air would have very little in common, as far as appearances go, with the water wave. The reason is that fluids like water are rather heavy compared to gases like air. It is the attraction of gravitation on the particles, either of air or of water, which tends to give the distinctive appearance of a wave. In fact we may consider a water wave as resulting from a competition between two forces, the energy of motion which the particle has received from the

wind which pushes it along horizontally, and the attraction of gravitation which pulls it down. In a sound wave in air, however, on account of the light weight of the molecules, gravitation plays an insignificant rôle, and such a wave, if we could see it, would probably look simply like a row of points which are alternately closely packed together and widely separated. Nevertheless we call it a wave, because the really important and distinctive thing about a wave is the fact that the particles are executing a periodic motion. Furthermore we draw

FIG. 4.—The Theory of Sound Waves in Air. The dots represent a row of molecules through which a sound wave is traveling. The molecules are alternately closely packed and attenuated as the disturbance passes.

pictures of sound waves and represent them by wavy lines although we are fairly certain that their actual appearance would be different.

In a water wave the particles at the trough have no energy. As a molecule rises towards the crest it gains energy of position, and when it has arrived at the crest it possesses its maximum amount of energy. Suppose we have two waves in water starting from the same point. Let these waves be similar with the exception that the wave-length of one, that is the distance between successive waves, is slightly greater or less than the wave-length of the other. You will see this best by making a diagram (see Fig. 5) in the following way. Draw a wavy line, such that the distance between the crest or the highest point of any wave and that of the next fol-

lowing is a certain measured distance, say one-half inch. Now, starting at the same place on the paper, draw another wave over the first with the difference that the distance between the waves is a little bit more than in the case of the first, say three-quarters of an inch. Looking at your diagram you will notice that although the two waves start out together, they gradually become separated; one goes a little faster than the other. After a time there comes a point where the first wave is at a crest while the second is in a trough. At this moment the two waves are

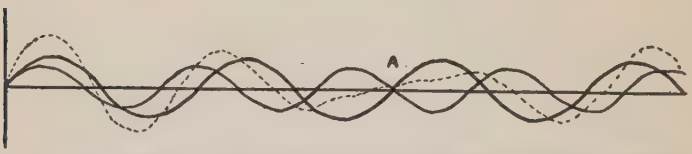


Fig. 5.—Showing how two sound waves, with slightly different wave-lengths, may fuse to produce silence. The broken line represents the resultant of the solid-line waves, or the one wave which is equivalent to the two. The horizontal line corresponds to zero intensity of sound, or silence, and where the broken line becomes almost coincident with it (as at *A*) the resultant of the simultaneous action of two sounds is silence.

exactly opposite, and if the energy of each wave is the same they will exactly neutralize one another. Thus from two water waves we have obtained for a moment a blotting out of one wave by another.

We may carry this picture without alteration to sound waves. If the wave-length of one of two sound waves is a little greater or less than that of the other, there will be moments when the two sounds will so fuse as to produce absolute silence. Reasoning again from your diagram it will be seen

that just half way between two points of silence the two waves must be in such a condition that their energies add up and produce a maximum amount of sound. If you strike two keys on a piano, so chosen that they represent what we call a discord, we are producing two sound waves at once with wave-lengths differing slightly. We describe the result as a series of beats, a sound which the ear can sometimes analyze into what seem to be alternate moments of sound and silence. Two sounds that have different wave-lengths, if made together, always produce beats. Music consists in discovering and producing combinations of sounds such that the beats obtained are pleasing to the ear.

CHAPTER VIII

INVISIBLE LIGHT

When we speak of "light" there come up in our minds visions of all that is beautiful and good and desirable in the world; and darkness suggests the opposite: the ugly, the wicked, and the things to be shunned.

It is natural that it should be this way, because Man feels safe and happy in the light and afraid and miserable in the dark. For in the kind light of day he can defend himself against enemies, while in the blackness of night he is prey to things unseen and horrible.

Light is what enters the eye when we "see" things, just as sound is what enters the ear when we hear things. But in ordinary talk we commonly make an error regarding "seeing." Suppose I am in a room with a person at night, and that the room has electric lights. I say that I "see" my companion. That is not accurate, because the light that enters my eye comes from the electric light and not from his body. You might more properly speak of seeing a firefly at night, because the firefly actually manufactures his own light.

The eye is certainly the most important of the sense organs. It is a marvelous arrangement of

lenses and other structures, and is the one portion of our bodies which is very sensitive to light. If one faces the sun, light strikes not only his eyes but also his ears and his nose; but it will be granted that the light has no great effect on his ears and nose. But when it strikes—or enters—the eye it passes to the back of that organ and comes in contact with the optic nerve which leads to the brain. This nerve is arranged to respond to light and to send a message to the brain when a ray of light strikes it. It tells the brain what the color of the light is and also how strong it is. And telling the brain is of course telling the individual, because so far as relations with the world are concerned, the brain is the individual.

Suppose, for example, you go out on a bright summer day and turn your eyes directly towards the sun. Instantly a rush message is sent to the brain, "White light—very, very strong—better do something about it as it's hurting me." And the brain—which is wiser than you are, if you look at the sun that way—takes the matter in hand and forces your eyes shut so that you will not injure them.

What is light, how does it originate, and how do we see things? This last we have answered sufficiently for our purposes.

In the chapter on energy we had considerable to say about the light that is produced sometimes when the chemical elements combine with each other. In this case the energy arising from the combination first takes the form of heat, and finally, when energy is being produced faster than heat can take care of, light begins to come. Light, we said,

then always comes after heat and hot things only produce light. But there are some exceptions to this. Certain insects, such as the firefly, seem to produce light without heat. Also some minerals have the peculiar power to absorb light in some way and later to give it out. Such a mineral, if allowed to remain for a while in the sunlight, will, later on, if placed in the dark, give up this light so that it seems to glow or to "phosphoresce" in the dark. This phosphorescence is accompanied by little heat, and will continue even if we place the mineral in as low a temperature as that of liquid air.

But for the most part our original statement holds, and we can discuss light as if it held absolutely.

Light is, of course, a form of energy. Furthermore light, like sound, is a wave motion. That is, it travels in pulses and not in one continuous stream. The speed of light differs enormously from that of sound. In empty space light travels at the terrific rate of 186,000 miles every second. Perhaps you are surprised that it takes any time at all for light to travel from one place to another. It does take time, but the time is so very small that it makes no difference ordinarily. For example, at sea on a clear day one can see about 10 miles. Suppose a light is turned on in a lighthouse ten miles away at 12 o'clock. How long before a man on the ship will see the light? At about 1/20,000 of a second after 12—which to all intents and purposes is no time at all.

So on the earth the fact that light takes a definite time to pass between points is of little or no impor-

tance. But where the distances are very great, as between stars, the time difference may become an extremely important factor. Thus it requires about one second for light to reach the earth from the moon, about eight minutes from the sun, and from a certain star many millions of miles away it takes more than *seventeen years* for light to reach the earth. To appreciate the full significance of this, suppose that this star had in some way been destroyed 15 years ago. If we looked now through our telescope we would still "see" the star, and indeed would continue to "see" it for two more years!

But, aside from this great difference in speed between sound and light—which makes sound a thing of this puny little earth only, and light a dazzling citizen of the whole Universe—there is still another and even more important difference between these two kinds of wave motion. Sound waves have to travel through some kind of matter. We recall the experiment of placing a bell under the glass and withdrawing the air, whereupon when the bell was rung no sound was heard. If instead of the bell we use an electric light in this experiment, we will find that the light glows just the same whether the air is present or not. Thus we have to conclude that light requires no matter at all to travel through. Light is the most independent thing in the Universe. Take away from its path everything we think is real—all matter, even air—and light goes merrily along, even faster than when matter is present!

Suppose we have a strong glass bottle containing

air and nothing else. Let us suck out this air with a strong pump. What is left in the bottle? Nothing? Nothing certainly in the sense of matter. But is there something left which is not matter at all and which we consequently cannot see, feel, or hear, and whose presence we cannot in any direct way verify?

The fact that light passes through such an apparently "empty" space (or "vacuum") has led many people to say that there was some substance present everywhere which is not matter and over which we have no control. This substance, they say, is continuous—that is, not made up of atoms—and can consequently pass through even the infinitely small spaces between the atoms and electrons of matter. This "substance" they call the "ether." (Do not confuse this "ether" with the chemical substance called ether which is used in hospitals. There is no connection between the two.)

People who believe in the ether say that it is the medium through which light travels, just as air is the usual medium through which sound travels. But they are compelled to give to this ether some very remarkable properties. They say it has no weight, and yet it is claimed that it must be so closely packed that even the densest of ordinary matter is like empty space in comparison.

People imagined the ether because it seemed necessary to have something for light to pass through. As a matter of fact, if we believe in the existence of the ether, the conduct of light is explained very well. But if the things we know about light could be quite as well explained in some other way, without

using the ether, then we would have no further reason for believing in it.

This is just what the brilliant scientist, Albert Einstein, has done. In a later chapter we will have more to say of him and his work. For our present purposes, suffice it to say that he has pretty well explained everything about light and much about other things, without once mentioning the ether. The surest way to kill a man's spirit is simply to ignore him. This is what Einstein did to the ether, and many people think there is no further necessity for believing in its existence.

It must be added, however, that there are still many persons, whose opinions demand great respect, who are not yet persuaded to abandon this pretty idea of a light, airy fluid which penetrates literally everywhere.

But, although light requires no matter to travel through, there is nevertheless one point in which it is firmly connected to our matter. Light always originates from matter. Just as a sound is started out by the vibration of some material body, so also light is produced by the vibration of some object. But the number of vibrations per second is very different in the two cases. For sound it may be several thousand; for light it runs into the millions! On account of the necessity of this great vibration rate for light, it follows that the vibrating body must be very, very small. The answer immediately suggests itself. It is the vibration of electrons, atoms, and molecules that produces light.

We say the *vibration* of the atoms, molecules and electrons causes light. But we are not quite so sure

nowadays as we were a few years ago that these small objects are actually vibrating in the same way as the metal strip in the last chapter was vibrating, that is, moving back and forth. We can say that the light which is produced acts as if it were a wave, a vibration, and ought therefore to be produced by a vibrating body. But in recent years Science has done some wonderful things, and the most wonderful of these is getting a definite picture of what an atom looks like inside and how it operates. These experiments give us a new picture of the production of light waves.

In the first place light is energy, and its production by atoms and molecules means that these atoms and molecules are releasing energy. The question immediately arises: Why do they give up their energy? There are many reasons for this. Sometimes it seems to be the desire of a group of atoms to combine in a different way; and in order to do this the system must release energy. We may consider that both the energy possessed by the atoms and the new state of combination are desirable things from the atom's point of view. But it must compromise; it must give up some of the one in order to attain the other.

Imagine a group of men—farmers, let us say—who wish to form an organization. There are arguments that occur to the individual farmer both for and against the proposition. In the organization he will find fellowship and he will probably get better prices for his crops than he could alone. On the other hand if he joins the organization he must plainly give up some of his independence and pool

his fortunes with the larger number. In the case of the atoms, the independence which they are giving up in order to get into the new combination corresponds to energy—the most valuable possession in the world, whether we speak of atoms or men. Thus very often when atoms combine energy is released. Sometimes this takes the form of heat; sometimes of light; and sometimes—most usually—of both together.

Or sometimes the atom has no choice in the matter; some agency, such as a man in his laboratory, may do something to the atom that forces it to give up energy. Thus X-rays (which are a kind of light) are produced by bombarding atoms with other atoms and electrons which are shot out with a tremendous speed. These fast-moving atoms and electrons knock out electrons from other atoms and the energy change gives X-rays. We may compare this to the bombardment of a city by heavy artillery. Suppose a shell strikes a high brick tower, knocking bricks out so that they fall to the ground. These dislodged bricks acquire energy of motion in their fall and if one of the city soldiers is below it may kill him by hitting him on the head, just as effectively as if he had been struck by the original shell.

In the last chapter we learned that sound always travels through the same medium with the same speed, but that the number of waves per second and the length of a wave can vary widely. Furthermore we saw that the number of waves per second (or the pitch) determines whether the sound is shrill or of the nature of a buzz. Now in light things are

precisely the same. The speed is always the same (for the same medium) but the wave-length and the number of waves per second may vary. Just as the pitch of a sound determines what kind of sound it is, so also the pitch (called *frequency* when referring to light) or the wave-length of light determines what kind of light it is, whether it is blue, yellow, or red.

What we call white light consists of a perfect blending of all the primary colors (the primary colors are those which cannot be produced by mix-

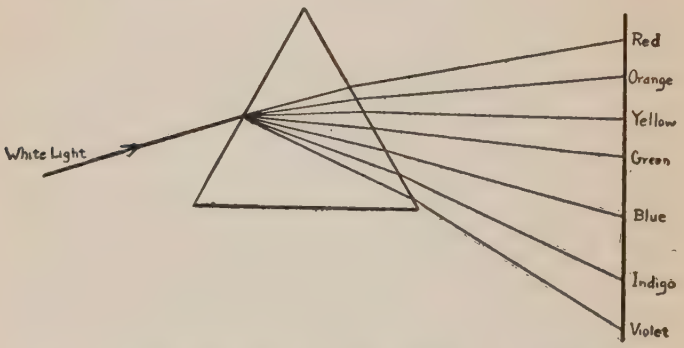


Fig. 6.—The Resolution of White Light by a Glass Prism into the Seven Primary Colors.

ing any other colors), red, orange, yellow, green, blue, indigo, and violet. That is somewhat like saying that a dollar bill consists of a number of nickels, dimes, quarters, pennies, etc. But in the case of light we can actually obtain the seven primary colors from pure white light. This can be done in the laboratory by passing a ray of white light through a piece of glass in the shape of a prism. The light

is bent in passing through this prism, and the different colors are bent to different extents, so that the light, on emerging from the prism, is seen to be separated into a broad band, red at one end and passing through all the seven colors to violet at the other end.

It may be mentioned that a rainbow is produced on a large scale in the same way, namely by the light from the sun passing through millions of little raindrops, which act the same as prisms.

The wave-lengths of these seven primary colors are very small and the number of waves per second very large; the red waves are longest and the violet shortest.

But suppose we have a wave a little longer than the red waves. We cannot see it, because our eyes are not arranged to see longer waves than the red; that is, such waves have no effect on the optic nerve, and no message is sent to the brain. But we can certainly feel these long waves. They are heat waves—nothing more nor less. Strange as it may seem, the only difference between light waves and heat waves is in their wave-length. Furthermore, if we consider waves that are still longer than the heat waves, we have the waves used in radio. For the visible light, it takes about a million of the waves placed together to make an inch; for the heat, from a thousand down to about a hundred or even less are required to make an inch; and you know from radio that the wave lengths vary from several meters up to several thousand meters (a meter is about three feet).

But is it possible to have waves shorter than the

shortest light wave, namely than the violet light? Yes, just a little shorter than the violet we have what are called the ultra-violet rays. These waves are important in medicine, for they have a germ-killing power and are able to penetrate down rather deep into the flesh whereas the ordinary visible light doesn't get under the skin.

It is chiefly the ultra-violet in sunlight which causes sunburn. That explains the puzzling fact that one can get a good sunburn about as easily on a cloudy day as on a bright one. The visible light cannot pass through the clouds while the ultra-violet comes through with much greater ease.

Still shorter than the ultra-violet we have the X-rays which are very powerful and if not handled with care may cause serious burns should they come in contact with the skin. X-rays pass through ordinary matter with ease, but are somewhat retarded by substances containing the heavy chemical elements, such as lead and iron. It is owing to this characteristic of X-rays that they are so useful to the doctor.

If you take a picture with a camera, you allow light to be reflected from the object you are photographing through your camera and onto the photographic film. If one part of the object is dark it will not reflect much light to the film; and if another part is light in color it will reflect much more light. Now a photographic film is a chemical mixture which is affected by light. When light strikes it, new chemical combinations take place, resulting in the formation of black metallic silver. The stronger the light, the greater the extent to which this takes

Rudolph Lesch.

W. C. Roentgen (1845-)
German physicist. Discoverer of X-Rays.

place. After the picture is taken the film is removed and placed in a liquid which dissolves away the chemicals that have not been changed, leaving the film transparent. But where black silver (finely divided metals such as silver all look black) has been deposited it is not affected by the solution, and so

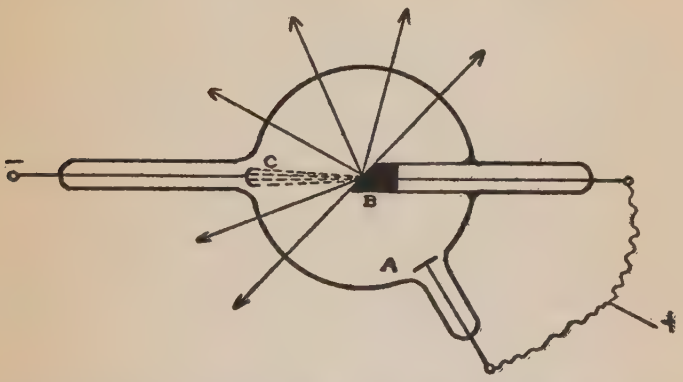


Fig. 7.—X-Ray Tube. Apparatus is made of glass; when complete all the air pumped out and the tube sealed. A very high electric potential is applied at + and —; this causes electrons to be expelled from the metallic *cathode C* and attracted by the *anodes B* and *A*. The shape of *C* is such that the electron stream converges in a point on *B*, as shown by the broken lines. The impact of the electrons against the metallic atoms of *B* produces X-rays, which are reflected in a hemisphere as indicated by the arrows.

there results after this "development" an image of the object you have photographed—but reversed because the light places in the object appear black and the dark places light. In printing from the negative, the image is again reversed so that on the print it is a true reproduction of the object.

Now in taking pictures with X-rays, instead of

allowing the X-ray "light" to be reflected from the object, we let the X-rays pass *through* the object and then to the photographic film.

A bullet is lodged in a man's leg, and the doctor cannot find it. He places the leg before a photographic plate and shoots X-rays through it. The rays pass through the flesh readily, through the bone with somewhat less ease, and through the lead bullet hardly at all. So when the film is developed the flesh of the leg will look black, the bone a little lighter and the bullet quite white. Thus the doctor is able to extract the bullet at once without undue pain to the patient, using the X-ray picture just as a man uses a city map to locate a certain street.

There are rays having wave-lengths still shorter than X-rays. Some of these are produced from radium (about which we will have a chapter later on). These very short rays are even more important to the physician than X-rays.

Very lately the famous American scientist, Millikan, has found rays even shorter than those from radium. They are continuously being sent to the earth from outer space and can penetrate matter so easily that they are found at the bottom of the deepest lakes and wells.

It is certainly entirely proper to speak of all these kinds of waves—radio, heat, visible light, ultra-violet, X-rays, radium rays, and Millikan rays, —as light. The only real difference between any of them is the wave-length. It is more common, however, to use the word "radiation" in referring to all of them.

In sound we mentioned the fact that some ears

might by accident be able to detect a sound of a wave-length by a little longer or shorter than can be heard by most people. That is also the case in light. Undoubtedly there are people who can see red of a little deeper shade or violet of a more intense hue than their fellow beings. But here we do not have to depend entirely upon the eye. We are familiar with the fact that certain kinds of crystals can "detect" radio waves. What is this "detecting" other than "seeing" the radio wave? Similarly a photographic film detects, or sees, an X-ray, and so on. It is well known that some animals are far more sensitive to the group of colors red-orange-green than to the group blue-indigo-violet. It may well be that their eyes can actually see (in the sense that we see ordinary colors) ultra-violet or infra-red (a little longer than red) radiation that is quite invisible to us.

If ultra-violet rays are produced in a certain lamp, no one can see them. But we can imagine that by looking at this lamp through some special kind of opera glass these rays might be made visible. Something of this nature was invented during the Great War, by the use of which American soldiers could signal to each other with this "invisible light" without the enemy observers being able to see anything at all.

CHAPTER IX

ATOMS OF ENERGY

We have said that light rays are produced by something happening inside the atom or very close to the atom. We learned that this event has to do with energy. But just what is it that occurs in the land of atoms to produce this wonderful phenomenon of light?

Let us remember that matter is made up of molecules, which are collections of atoms. Furthermore, we know that each atom is a wonderful structure of whirling electrons. In the land of atoms everything is moving, and moving very fast. In the atom there is a center—about which we know very little—and around this center electrons are whirling at great speeds. The electrons move around the central core sometimes in circles and sometimes in paths which look like circles which have been stepped upon and are partly squashed—ellipses. Some of the electrons are very near the central core, and some farther out. If we could by some magic suddenly stop the motion of the electrons in an atom and have each electron remain motionless, we should see something that may be described as a number of shells formed by electrons—like a lot of balls made of coarse wire netting and fitting inside one another. We might number these shells, 1, 2, 3, etc., from the central core outwards.

Let us consider an electron in shell number 2. Evidently it will require work if that electron be removed, say, to shell number 3, for the same reason that it requires work to lift a stone from the foot of a hill to the top. If, however, we perform that work and take our electron from shell 2 to shell 3, the electron will have gained an amount of energy corresponding to the amount of work required to move it.

Now let us reverse the process and in some way dislodge the electron from shell 3 and make it fall back to shell 2. Evidently it must give up the difference in energy between shell 2 and shell 3, just as pushing a stone off a cliff causes that stone to do work on the ground beneath by striking it hard.

Now we may state the matter very simply by saying that this energy given up by an electron in falling back towards the center of the atom takes that form which we call light, or more generally, radiation.

But what makes the electron fall? The atom is rather a delicately balanced machine; if nothing occurs to disturb it, it will remain unchanged. But suppose the atom were as large as a baseball and someone shot a bullet through it. The bullet might happen to hit an electron. If it did it would disturb its whirling motion and it would fall down toward the center. Or two atoms might happen to strike each other, especially if they are being heated up so that they move about with great speed. An electron might be dislodged in this way, or in other ways which can easily be imagined.

In each such case energy is sent out from the

atom and this energy very often is in the form of light or of X-rays, etc. So a flash of light is an atom's way of telling us, "One of my electrons just made a pretty jump from shell 4 to shell 3."

But that isn't quite the whole story. Not only are the electrons moving, but also the atoms themselves as wholes are moving about in certain definite curved paths. Sometimes, for some reason or other, the motion of the atoms is changed and the difference in energy comes to us as radiation. Also the molecules are in motion, and by a similar process, we may get light from changes in their motion.

So we can say that a molecule has a certain amount of energy because of its motion, and of the motion and positions of the atoms and electrons that make it up; and that when the total amount of energy is decreased from any cause, the molecule gives out radiation.

Of course the energy given out in such a case by one single molecule is far too small for us to detect in any way. But if several millions of them happen to do about the same thing at about the same time, then all the little bits of energy add together and make enough for us to see.

And now comes something that is far more amazing than anything that has gone before. And we must continue to be amazed, because no one knows just why it is so. An explanation would seem to approach dangerously near to a First Cause.

It was stated that when an electron is dislodged from shell 3 it falls back to shell 2. Why does it have to fall all the way back to shell 2? There is a certain space, a certain distance, between the two

shells, and it looks, offhand, as if the electron might fall, say, half-way from shell 3 to shell 2 and stop there. But it never does. We don't know why—all we know is the fact.

There is another remarkable thing about this. How long does it take for the electron to travel between the two shells? As nearly as we can find out, it seems to take no time at all. The electron is in two places at once! That is another mystery. It seems as though the land of atoms has no time as we understand it.

Let us see just what this fact that electrons have to go the whole distance between shells or none at all, means. Plainly, if energy is sent out because the electron falls, we can guess that the greater the distance of fall, the greater the energy released. But if this is true it follows that the *smallest* amount of energy that an atom can release corresponds to the distance between its two shells that are closest together.

Suppose the push that the electron received was so great the next lower shell could not stop it. It would pass through and start for the next shell toward the center. But again—like an elevator which can only stop at floors and not between—the electron must go all the way to the next shell or none at all. There is no resting place between shells.

Matter is made up of very small particles which in no way that we know can be further divided. From the above it looks as if the same must be true of energy. The fact that the electron cannot stop between shells means that we cannot have an amount of energy smaller than a certain very small

quantity. And further it means that when we see a light, this light is composed of millions of these little "bundles" of energy,—just as a piece of matter is composed of its atoms.

We can then with perfect accuracy speak of atoms of energy.

CHAPTER X

ELECTRICITY AND HOW MATTER AND ENERGY MAY BE THE SAME

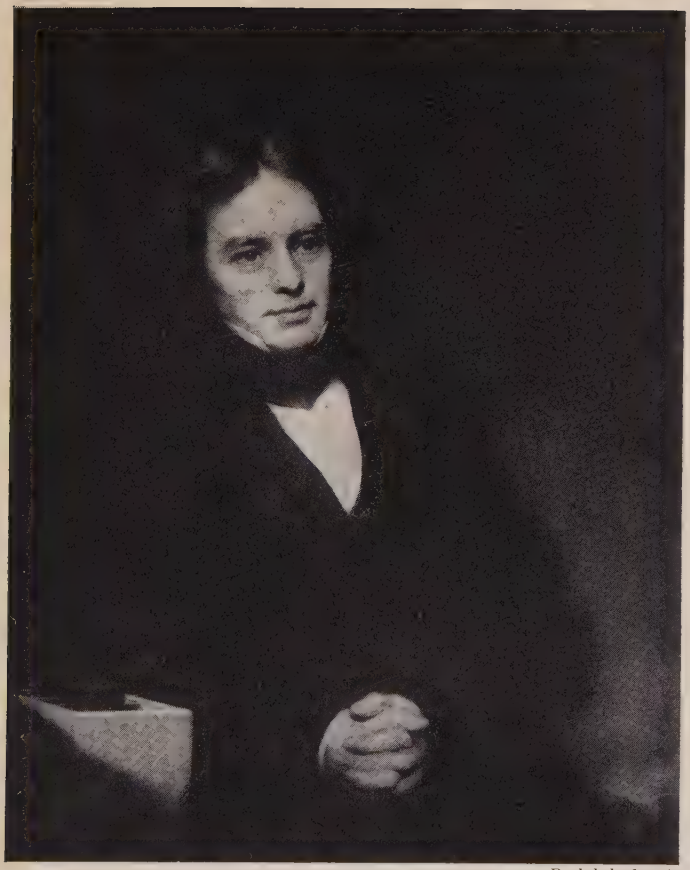
MANY people like to think that electricity is some altogether new thing that was brought into being from nothingness by the great modern inventors like Edison and Marconi. This is far from the truth. When the first atom of matter appeared in the Universe—and we don't yet know how or when it appeared—electricity was born. The ancient Greeks and Romans had no electric lights, no telephones, no radio, no street-cars, no electric heaters. But it was not because there was no electricity in those distant days. It was simply that these men had not yet learned what electricity was, where to find it, and how to build machines to make use of it. For after all, the telephone, the electric light, the radio, and all the other thousands of electrical devices we use so freely to-day, are nothing but clever machines to *make use* of electricity. The electricity has been here all the time. Even in the days of the Greeks and Romans great lightning storms now and then possessed the skies. In each lightning flash there was enough electricity to supply the whole of ancient Greece with the electrical conveniences we now enjoy.

But our present-day electricity does not come

from lightning flashes a mile in length, but rather from that extremely minute friend of ours—the atom. The atom is truly a structure of surpassing complexity. In it are powerful and delicate machines, hidden away from the casual visitor. But if a man will seriously investigate this universal building stone, if he will spend his lifetime reverently studying the astounding things that go on there—he may be rewarded at last with a secret that will make the world a better place in which to live.

Light we know comes from the atoms. It has taken many men whole lifetimes to discover that for us. And here within a few pages we shall learn how electricity is now known to have its origin also in this mysterious, delicately balanced microcosm. But let us not forget that this knowledge which we have to-day and of which I am giving you a skimpy outline, came to us chiefly through the efforts of men to whom the understanding of the world about them was a ruling passion, men who were glad to give up the soothing comforts and the simple joys of an ordinary life; or the self-importance that comes to leaders of men and conquerors of nations, —who were led to forsake all these things, and often to live in stinging poverty, to labor in cold garrets, and to suffer the gnawing torments of physical hunger. And all for what? For that great peace, that calm and certain satisfaction that comes to the human mind, of having conquered the world, not by the strength of muscles, nor yet by cleverness in handling other men,—but by the sheer, unaided force of the human mind itself.

Let us imagine an atom with nucleus and elec-



Rudolph Lesch.

MICHAEL FARADAY (1791-1867)

English chemist and physicist. Made many discoveries in electricity, among which were the principles underlying the production of electric energy from chemical changes in batteries.

trons the size of billiard balls, so that we can see and handle them. Let us stop the motion and take out two electrons, and try to push one towards the other. We are surprised at the difficulty of this operation. It would appear that these two electrons are sworn enemies; they do not wish to come together. If we have strength enough we might get them very near together, but it becomes plain that these two electrons repel each other with a very considerable force. That is rather strange, and it is something we should never have suspected. In fact, if we think of bodies on the earth and gravitation, it appears to us that it ought to be the other way around, that the electrons ought to *attract* each other. But here it seems we have something different altogether from gravitation in larger bodies of matter.

Now let us bring one of our electrons nearer to the central core of the atom—the nucleus—and see what happens. Again we are greatly surprised. The electron and the nucleus do not repel each other, but on the contrary *attract* one another very strongly. We have to exert great strength to hold them apart if they are at all near together.

Now we know this to be a fact about the atom. We know that the electrons all repel one another and that the nucleus attracts all the electrons. But this is all we do know about it. Let us imagine a substance of such a peculiar nature that different portions of it repel each other. Let us say that each electron has some of this substance. That will account for the repulsion between electrons. Now if we say that the nucleus has some of this mys-

terious substance, *but not enough—not as much as it needs,* then we can understand why the nucleus attracts the electrons which have what it wants.

All we need to do now is to give this substance a name—*electricity*—and we have told about all we know of what electricity really is. We have called it a "substance," but only for convenience of description. Electricity is not a "substance" in the sense in which we apply that word to matter.

Now this tells us what electricity is, but it certainly gives us no clew whatever as to how to get this electricity out of the atom and into our machines to be made useful. To understand this involves the understanding of magnets.

Every boy has at some time owned and played with a little red horseshoe magnet. But one would not imagine the important part such a little toy could play in the great electrical machines. There are only a few metals of which magnets can be made. By far the most commonly used is iron. We are not certain why magnetism is thus limited to a few metals. Probably it is because of some peculiar shape that the molecules of these favored metals have.

At any rate it is probably correct to say that an iron molecule in a bar of that metal can be distorted, if we know how, so that the electrons are pulled somewhat to one side. That means of course that there comes to be more electricity on one side than on the other. Suppose we have a bar of iron a few inches long consisting of a single row of iron molecules, and imagine that in some way all these molecules become distorted so that one side of each

molecule has more electricity than normally and the other less. If now each of the molecules has its electrons displaced in the same direction, say to the right, we can consider that the bar as a whole has more electricity towards its right end than towards its left end.

Then the bar of iron is a magnet. If now another little bar of unmagnetized iron is brought near its

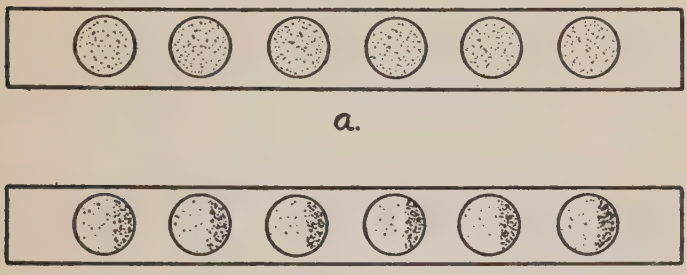


FIG. 8.—The Theory of Magnetism. In an unmagnetized bar of iron the molecules have their electricity evenly distributed throughout their masses, as represented in *a* by the even shading in the circles. When the bar is magnetized the electricity is pulled to one side and the molecules become *polarized,* or electrically distorted, as in *b*.

right end, the excess electricity on that end will distort the molecules in the small bar and make a second magnet of that bar. The end of this new magnet which has excess electricity will be repelled by the right end of the first magnet, just as two electrons repel each other. But the opposite end of the new magnet will have too little electricity and will therefore be attracted by the right end of the first magnet, causing them to rush together if not

held firmly. That is why a magnet will attract other small pieces of iron. First it makes magnets of them and then attracts them.

Bars of iron can be magnetized, as above, by treating them with other magnets. But if no other magnet is available it is possible to make a magnet by coiling a wire around the bar and sending an electric current from a battery through the wire (not through the iron). If the bar is of soft iron it is very easy to magnetize it in this way. But since the metal is soft and the molecules somewhat loose, the magnetism will not last long; the bar gradually returns of its own accord to the unmagnetized condition. If, however, we use a bar of hard iron or steel, it is much more difficult to magnetize it, but, when it is once made into a magnet, it will stay so indefinitely.

Consider a magnet lying on the table. It is perfectly still and we know that if we should bring near it a piece of iron it would exert a pull on that piece of iron, drawing it towards the magnet. If we examine the space around the magnet to find out if there is any difference in the pull it exerts at different points, we find that there is such a difference. Not only does the pull decrease as the piece of iron is moved farther away (the same way that gravitational attraction decreases with distance) but it also becomes less as we approach a point on the magnet which is just half way between the two ends (these ends are called poles). As we go away from this central point towards either pole the attraction increases, until it is greatest immediately at a pole.

It is convenient to consider that the space around a magnet is in some way affected by the magnet's mere presence even though there is no other piece of iron in the neighborhood to be attracted. We say a *magnetic field* exists around the magnet. This is similar to the statement that a gravitational field exists around the earth, by which we mean that the ability of the earth to attract other bodies to it exists whether there are bodies present to be attracted or not. It is like the illustration used earlier in this book of a person sitting in a chair, not moving, and yet knowing that if he wanted to do so, he could rise and walk across the room. Just as that belief on his part represents confidence in himself derived from experience, so our idea of a gravitational or magnetic field represents our confidence in magnets and bodies of matter to act in the future just as they have always acted in the past.

If we could examine a section of copper wire in our imaginary laboratory we should see that some of the electrons in the copper atoms are rather loosely held. They seem to be able to move about with considerable freedom, transferring their allegiance readily from one atom to a neighboring one. But there is no regularity in this motion. An electron moving like that is as likely to go to the right as to the left.

Suppose that we take such a copper wire and twist it into a closed circle. Now move the wire circle near a magnet so that it passes through the field of force of the magnet. Each pole of the magnet, since it either has electricity or needs electricity, exerts a force on these loose electrons in the copper

wire. And if now we observed the wire with our super-microscope we should see that besides the irregular confused motion of these electrons in all directions, there appears a slow drift of the whole lot of them in one direction; what this direction is depends on which pole of the magnet the wire coil is moved towards.

This drift of electrons means that electricity is being transferred along the wire. That is what we term an electric current (current means something flowing). Electricity is energy and therefore electric current is flow of energy. It is therefore a powerful agent for doing work, as we shall see.

We stated in an earlier chapter that we cannot create energy, we can only change it from one form to another. In our experiment of moving the wire coil through the magnetic field, we have produced a flow of electricity through the wire, and hence have obtained energy. But our conviction that we have not, in doing this, created energy out of nothing, leads us to search for the energy we used as a starting point for this transformation.

This is not a difficult task, for it is evident that it requires work, and hence expenditure of energy, to move the wire coil. On actually measuring this work, we discover that even more work is needed to move the wire along when in the neighborhood of the magnet than when distant from it. It is found, as we should expect, that the total energy used is exactly equal to the electrical energy represented by the current produced.

We have found that there is plenty of electricity in every atom of matter, but in order for that elec-

tricity to be useful it is necessary for us to make it move. We can produce motion of electrons from one end of a wire to the other by moving that wire through a magnetic field. Let us then construct an engine made up of a magnet which remains motionless, and a wire which is made to move in the neighborhood of the magnet. It will be easy to conceive of many mechanical arrangements by which this could be effected. Any one of them would give us electrical energy in exchange for mechanical. The mechanical energy may be derived from water flowing over a fall, as in the great electrical generating plant at Niagara Falls. Or the mechanical energy may be produced from the latent energy of coal and air, through a heat engine of some sort, as is done in most of our smaller electrical generating plants where there is no water power available.

We said that any arrangement that will move wires through magnetic fields would serve as a generator of electrical energy. That is true, but it is also to be understood that out of all the many types possible there are some which are easier to construct and manage, and which will do the work required with smaller losses of energy due to friction, than the others. Thus it is that the electric generators found in power houses to-day may be difficult to connect up with a simple wire moving through a magnetic field. There are many magnets and many small coils of wire, instead of just one of each. Sometimes the wire coils are kept still and the magnets moved around them, and sometimes the reverse is done. Any dynamo (for such is the name given to engines which produce electrical energy from

some other kind) will appear to the layman as a very complicated arrangement of wheels and brushes and things. But he needs only to remember that when the dynamo is stripped of all the various little improvements and complications that make it do the work better, when it is considered in its simplest form, it always comes back to a wire moving through a magnetic field of force.

Having obtained electric current from our dynamo, how may it be put to use to make life more comfortable and to release mankind from the drudgery that was its lot before the present Age of Invention?

One such way is to reverse the operation of the dynamo and make what is called an electric motor. When using the dynamo we have at hand mechanical energy and we desire electrical energy. But in the street-car, for example, the opposite is true; we have electrical energy from the power plant and we wish to produce mechanical energy in order to turn the wheels. For this purpose we employ a motor, in which, instead of moving a coil of wire in the neighborhood of a magnet and generating an electric current in the wire, we pass electricity through the coil of wire and thus make it move through the magnetic field.

In the telegraph and telephone, in electric bells, and many other such devices, a somewhat different use is made of magnets. Above we stated that when a bar of hard iron is magnetized it retains its magnetism indefinitely. But if we pass a current of electricity through a wire coiling around a bar of *soft* iron, we find that, although a much smaller

current is needed to produce magnetization, the magnetism remains for only a very short time after the current is stopped. Suppose then that we built an arrangement something like this: a bar of soft iron with a coil of wire around it connected to a battery. Near one end of the iron bar is a second strip of iron fixed at one end. If we allow a current to flow through the wire for a few seconds the bar will become a magnet and will therefore attract the iron strip and cause it to bend down and make contact with it. Now shut off the current and the magnetism will cease and the strip will no longer be attracted and will fly back to its first position. If we place a piece of brass in such a position that the strip when flying back strikes it and makes a click, we have what amounts to a telegraph system. Instead of connecting and disconnecting the wire to the battery, we can put in a telegraph key, which when pressed down connects the wire to the battery and when released breaks the current. Every time we press the key we hear a click on the *sounder* and by holding the key down for a shorter or longer time we make the "dots and dashes" by which messages are spelled out according to the telegraph code. It will be readily understood that the key, the battery, and the sounder must not necessarily be in the same room. The key and battery may be in New York and the sounder in Chicago, as long as they are properly connected by wire. Thus it is that messages can be sent by telegraph across the country, or even through cables under the ocean to Europe.

In the telephone the general idea is much the

same but the apparatus is more delicate and complicated. The telephoner speaks against a thin circular disk of steel. This disk is so delicate that the vibrations of the voice cause it to vibrate in the same manner.

The vibrations of the disk are changed into electricity in somewhat the same way as the motion of the telegrapher's hand is changed into electricity, and are transmitted over wires to the person who is listening to the message. The electrical impulses

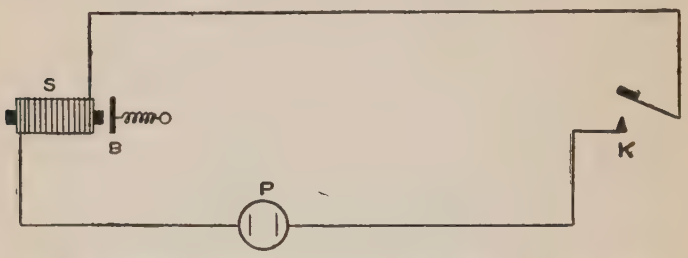


FIG. 9.—Diagram of a Simple Telegraph Circuit. *P* is a battery, or other source of electric energy which, when the key *K* is closed, sends a current through the coil *S*. This causes the core of soft iron to become a magnet and attract the iron bar *B*, which touches it, making a click. On releasing the key the magnetic attraction ceases and the spring pulls *B* back.

in the receiver cause little currents to flow in the wire around the magnet in that instrument. In the receiver is another thin disk of steel which is set into vibration by these magnetic currents. It is evident that the vibrations of the disk at the receiving end will exactly match those at the sending end, and so out of the receiver seems to come the voice of the person at the other end, which may be several thousand miles away.

When an electric current passes through a wire the wire becomes warm. This is easy to understand, because we know that an electric current means electrons flowing along a wire. These electrons are bound to strike against molecules now and then and to increase the vibration of these molecules and thus increase the heat in the wire. If the wire is made very thin and the current made great the wire will become very hot. Some of the electrical energy is wasted in heating up the wire. In the telephone and telegraph this is indeed a waste because we aren't interested in the wire getting hot. But it was not long in occurring to inventors that a virtue could be made of this apparently unfortunate conduct of electricity. We have such devices in our homes everywhere. Electric heaters, toasters, stoves, etc., are all such arrangements of small wires through which electricity is passed, causing them to become hot. In the electric light we carry matters a bit further and make the wire so small and the current so large that not only the molecular vibration is increased, but even the vibration of electrons and atoms is affected. This we know produces light, and so an electric lamp is an engine for changing electrical energy into light energy.

The reader may be puzzled by the fact that although the glowing wires in the electric lamp are much smaller than the wires in an electric toaster, nevertheless the toaster gets much hotter than the lamp. That is because the wires in the toaster are in contact with air while those in the lamp are in a space from which almost all the air has been removed. Heat energy is transferred from one point

to another either by radiation (like light) which travels through a vacuum; or by jumping from one air molecule to another. If we remove the air we remove one of the means of the transmission of heat and accordingly lessen the heat loss, which is of course to be desired in electric bulbs.

CHAPTER XI

ALTERNATING CURRENT AND THE RADIO

In a simple generator such as that described in the last chapter, on account of the circular motion of the wire coil through the magnetic field, the electric current which is produced goes in one direction half the time, and in the other direction around the coil the other half. When we wish to obtain current going always in the same direction, *direct current,* we introduce a device called a commutator, which reverses the polarity, that is, which alternately makes one of the wires leading from the generator the positive and the negative side of the line.

But if we use the generator without the commutator, we obtain a pulsating, surging electron flow, first in one direction and then in the other. This is *alternating current.* The direction of the current reverses once every time the rotating part of the generator moves completely around. Plainly, then, the faster the generator is running the greater the number of alternations per second. The usual frequency is sixty alternations per second; such a current is called sixty-cycle current and is what is furnished to us by most electric power companies for our household lighting systems. Since there is a natural mechanical limit to the speed at which the rotor of the generator may revolve, frequencies

higher than a few thousand cannot be produced by this method. The newly invented three-element vacuum tube, which we shall presently describe, enables us to produce alternating currents of several million cycles per second.

Alternating current is preferable to direct current, especially when the generating plant is located at a great distance from the town which is to use the electricity. If an alternating current is allowed to flow through a coil of wire, and if, close to this first coil, another coil is placed, a similar alternating current will be *induced,* as we say, in the second coil, which, note carefully, is not directly connected in any way to the coil in which the current was originally flowing. It is somewhat the same as the sympathetic vibration of one tuning fork to another, as we learned in the chapter on sound.

One way of describing any electric current is in terms of the *voltage,* which is the electrical pressure. It is what determines the intensity with which the current will flow if released. An electric current flowing through any conductor always meets with a certain resistance. The voltage determines to what extent the current will overcome this resistance. Thus if you are trying to force electricity through a very long wire, you will get a larger current by using a six-volt battery than by using a one-volt dry cell.

In the case of an alternating current, if it is desired to transmit a large amount of power one has the choice of sending it over the wires either at a low voltage and high current value, or at a high voltage and low current. We can send the same amount of power over the wire either way. With

direct current, however, we cannot change the voltage without changing the generator. But with alternating currents the fact that energy can be transferred across space between two coils, as described above, enables us to juggle the current and voltage about at will. This is done by means of what are called *transformers.* These instruments are simply boxes containing two coils of wire which function like the two coils described in the beginning of this chapter. The alternating current enters at one side of the transformer and flows through one coil. If the two coils have each the same number of turns of wire the current induced in the second coil has the same voltage and the same current value as that which is flowing through the first. However, if the first coil has, say, one hundred turns and the second only ten turns, the voltage of the induced current will be one-tenth of that of the current in the first or primary coil. The current strength or *amperage* is correspondingly increased ten-fold.

When an electric company is faced with the problem of transmitting power over copper wires for many hundreds of miles, the question of how much of this electrical energy will be wasted due to the heating up of the wires, becomes of importance. The heating effect of a current increases very swiftly as the amperage is raised. Therefore it is desirable to transmit the current at as low an amperage as possible. The general practice is to generate the energy as alternating current at the plant at about five hundred volts, because generators work well at such voltages. The current is then, by a transformer whose coils have the proper number of turns,

"stepped-up" to a higher voltage, such as twenty thousand volts. That gives us a very low amperage so that wires of small size may be used for transmitting the power to the city where it is to be used; there, by means of "step-down" transformers, it is changed to a lower voltage for use in house lighting circuits. The high cost of copper wire makes this a factor of great importance.

In alternating currents of frequencies of only a few hundred we find nothing of great interest. As we pass, however, to very high frequencies of the order of several hundred thousand or even a few million we begin to meet with a property of these currents which has been put to the most astounding uses in this Age of Invention.

Where we have an alternating current of very high frequency flowing through a wire, we not only have a condition of very swift motion, for these electrons are moving with the speed of light (186,000 miles a second), but what is more important, we have this electron motion changing its direction several hundred thousand times every second. It is rather natural to expect that such a violent disturbance would make itself felt by some extraordinary new characteristic developed by the circuit carrying these high frequencies. We find, indeed, that in these cases the wire through which the current is flowing acts as a center from which a disturbance is transmitted in all directions. This disturbance is a wave motion in the sense that light is a wave motion, and, indeed, these *electromagnetic radiations,* as we call them, are in every respect perfectly similar to the radiations of visible light, X-rays, etc.

Rudolph Lesch.

HEINRICH HERTZ (1857-1894)

German physicist, student of Helmholtz, who discovered, in 1887, the electric waves (called sometimes "Hertzian Waves" in his honor) which form the basis of modern radio.

We learned that light is caused by the jumping of an electron. In other words the electron makes a sudden and violent change in its condition of motion. Bearing this in mind one might have predicted that the sudden reversal of direction of the electron flow in conductors carrying high frequency current would give rise to a similar effect. That prediction would have been entirely justified, for electromagnetic radiation is identical with light, with the single exception that, whereas light waves have lengths which are measured in very small fractions of a millimeter, these radiations which we are now considering may vary in length from somewhat below one meter to many thousand meters.

These waves sent out by alternating current find their greatest use in radio. We shall therefore designate them as radio waves. As stated before, they travel with the speed of light, 186,000 miles or 300,000,000 meters a second. Either one of these figures divided by the frequency, or the number of waves per second, gives the distance between crests or troughs of adjacent waves, or the wave-length. Thus if you find that the wave-length of a certain broadcasting station is 300 meters, this number divided into the speed of the radiation, gives 1,000,000 which is the number of alternations per second or the frequency. That means that both in the broadcasting station and in your receiving set electrons are changing their direction of flow a million times every second.

In light you remember that the frequency or the wave-length is what determines the color. In other words the characteristics of visible radiation are

determined by the frequency. It is to be expected, then, that the same would be true of radio waves. We find that this is so to a very remarkable extent. Where the wave-lengths are from a hundred to a thousand meters, the intensity of the wave gradually decreases as we go away from the sending station in any direction. If however we use waves below forty meters we find that matters are entirely different. The waves seem to jump around from the sky to the earth in a manner quite erratic. In the case of certain wave-lengths it is practically impossible to pick up the signal within five hundred miles of the transmitting station. From that point on the wave gradually *increases* in intensity, until at a distance of about five thousand miles from the sending station the signal reaches its highest strength. On account of this remarkable fact, an amateur radio operator with a small-powered set is able to sit in his home in California, say, and talk back and forth almost every evening with Japan and Australia, and with the countries in Europe,—although sometimes he cannot be heard in the State of California.

Still more striking is the fact that while the wave-lengths used by broadcasting stations enable the signals to go much farther at night than in daytime, an amateur working on twenty meters is able to traverse continents and seas in broad daylight, but can only with difficulty be heard out of the State on that wave-length at night. The reason for this remarkable behavior is still quite obscure, and one dares not predict what other strange things may come out of work with very short radio waves.

The key to the understanding of modern radio is the vacuum tube, to which we have made reference and with which you are doubtless to some extent acquainted. If a fine filament of a metal like tungsten is heated until it glows white, it has been discovered that electrons are, so to speak, boiled off from the surface of the white-hot metal. In the vacuum tube there is such a filament which is heated by means of a small "A" battery to a temperature high enough for it to give off electrons. In the tube, close to the filament but not touching it, is a flat sheet of metal called the *plate*. This plate is given a positive electrical charge by connection to the positive side of a "B" battery (usually a battery of dry cells). The negative pole of the "B" battery goes to the filament, so that the circuit from the filament through the plate and the "B" battery and back to the filament is closed, except for the space between the plate and the filament. But if the filament is hot and giving off electrons, these electrons being negative electricity are attracted to the plate, which has a positive charge. There is consequently a flow of electricity across empty space (the air is removed from vacuum tubes) between the filament and the plate. As the matter stands now, a vacuum tube, consisting of a filament and a plate, "B" battery and "A" battery, if connected in the proper manner, will

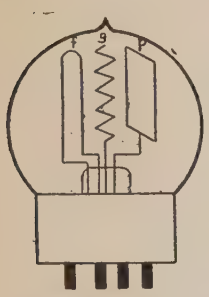


FIG. 10.—The Three-Element Vacuum Tube. *f* is the filament, *g* the grid, and *p* the the plate.

allow a simple direct current to flow around the circuit. In the modern tube, however, a third element called the grid is interposed between the plate and the filament. The grid is connected to the antenna of your receiving set.

The radiation which is sent out from the antenna of the broadcasting station has the peculiar power, whenever it strikes another antenna, of transforming itself back into an alternating current of the same frequency as that from which it originated. Thus in our receiving antenna a weak current is set up which is precisely similar to the current sent out by the broadcasting station. That is, it alternates from positive to negative the same number of times per second. Thus the grid of the vacuum tube is given first a positive charge and then a negative charge. When the grid is positive it pulls towards itself the electrons which are being boiled off the hot filament, and consequently the current which passes is made slightly greater. If the grid then becomes negative it repels the electrons and slightly reduces the current flow. By this we see that the grid, which is charged with the infinitely small quantities of electricity which enter the antenna, is nevertheless able to control the comparatively enormous current which is flowing from the "B" battery of your set. A slight pressure of your finger applied to the trigger on a revolver causes the release of the large amount of energy which we know to be associated with the bullet as it leaves the muzzle. The idea is the same.

If we picture alternation from positive to negative as up and down motion, it becomes possible to repre-

sent an alternating current as a wavy line. If we choose a given length to represent one second, then the number of waves contained in that length gives us the frequency of the radiation; the distance between waves is the wave-length. The current flowing in a vacuum tube in which the grid is not connected, is constant, that is does not go up or down, and therefore may be represented as a straight line. With the grid connected to an antenna where high frequency current is flowing, the action of the grid causes the straight line "B" battery current to assume a wavy form, and the number of waves per second is exactly the same as that of the incoming radio wave. By the device of the vacuum tube the very weak antenna current is used as a sort of mold for producing a large current of similar form. Although the small antenna current is usually too weak to affect our telephone receivers, the large modified current from the "B" battery can do so.

We have described above what happens in your receiving set when a radio signal is heard. To make the picture complete we must discuss for a moment how these high frequency currents are produced in the broadcasting station. Much larger vacuum tubes are used because the amount of electrical energy handled in a broadcasting station exceeds by far that in a receiving set. When the vacuum tube is used as a generator of high frequency current the grid, instead of being connected to the antenna, leads to a coil of wire the other end of which is connected to the negative side of the "B" battery, the plate as usual being connected to the positive side. To the middle of the coil of wire is attached an instrument

called a condenser, which in its simplest form consists of two metal plates separated by a small air space. One of these plates is connected to the coil and the other to the filament. When the batteries are turned on and the apparatus "hooked up" as described, an alternating current of high frequency is produced and flows through the coil.

It is not difficult to understand how the grid acts to chop up the direct current and make it alternating. First of all, electrons are shot off the hot filament, passed to the plate, through the "B" battery and around through the coil of wire. Bear in mind that the other end of this coil is connected to the grid while from the center of the coil connection is made through the condenser to the filament. Now the electrons which enter one end of the coil go partly back through the condenser to the filament, and partly to the grid. Thus the electrons gradually pile up on the grid, giving it a negative charge. When this negative charge becomes great enough it will repel the flow of electrons from the filament to the plate, and to reduce the strain which is set up the current must flow for a time in the opposite direction. When the grid is again free of electrons the current once more changes direction. If this happens many times per second we have a current flowing in the circuit which alternates in direction very fast; in other words we have a current of high frequency, or, as it is called, a current *of radio frequency.*

In a simple transmitting set like that which we have described, arrangement is provided for making the coil of wire long or short, and for varying the

distance between the metallic plates of the condenser. By so doing we change at will the frequency of the current being generated. This is called *tuning* the circuit. When you turn the dials on your receiving set you are doing essentially the same thing, changing the sizes of your coils and condensers and thereby putting your instrument "in tune" with the broadcasting station.

What we have said thus far about modern radio applies only to radio telegraphy. Just as in land telegraphy the current is interrupted by means of a key into dots and dashes to form a message. In the last chapter we learned that the vibrations of speech were translated into electrical terms by speaking against a disk which is caused to vibrate and modify the current to match the sound vibrations. So in radio telephony the radio frequency current is made to pass through a *microphone* which consists of a metal disk resting on a layer of finely divided carbon. Sound waves striking the disk change the pressure on the carbon dust, and alter the shape of the radio frequency waves to conform to the sound waves. In the receiving set the current wave, after being cut in half by the detector, is passed through an ordinary telephone receiver. The disk in the receiver is quite unable to vibrate at the radio frequency rate, but can vibrate to conform to the sound wave which, in a sense, is riding on the radio wave. Do not make the mistake of imagining that the actual sound wave which is spoken into the microphone at the broadcasting station, is what reaches your ear. Sound is first translated into electricity, sent through space with the speed of light, and then

in your receiving set the reverse thing is done,—electricity is again translated into sound.

There is one more thing we must mention when speaking of radio. That is the possibility of the transmission of power for household and industrial purposes over great distances by means of radio. If this could be done it would mean, for one thing, that the cost of electrical energy would be greatly reduced, because in the present-day systems of wire transmission the copper wire is an item of very great expense. It may be that some day all sorts of things will be broadcast by radio in the form of electricity, to be translated in our homes and factories into the desired types of energy, just as now we transmit sound energy in such a way entirely around the earth.

CHAPTER XII

BRINGING THE SUN DOWN TO EARTH

From the very earliest times men's attention has been held by the great white orb that untiring wends his daily way across the sky. As light means to us to-day all that is good and beautiful, so the sun by our ancestors of olden times was regarded as some smiling beneficent god who showered goodness and beauty continually upon us; for in the dim past ages when the human race was just beginning the long struggle towards civilization, fire was unknown, and the sun was the only source of light and warmth.

First men feared the sun. So different it was from things on earth, so distant and yet so powerful, so important to man's well-being, and yet so utterly beyond his control, so mysterious in its risings and settings, so defiant of understanding. And with fear came the conviction that the great glowing disk was a thing alive who ruled the earth and the heavens and who therefore must be worshiped and sacrificed to. In Mexico now one finds occasionally remnants of an ancient people, the Aztecs, who worshiped the sun and built great mounds like the Egyptian Pyramids to his honor.

But as the long centuries unrolled, Man slowly learned to know the sun in its true nature, not as a

god to whom we must bow down, but as a great white-hot, half liquid, globe, millions of miles off in space. They learned that the sun does not stand alone in the Universe in its brilliant grandeur, but that each twinkling star we see on a fine night is another sun, most of them far larger than our own sun, yet separated from us and from our sun by distances which are measured by trillions of trillions of miles.

Originally, when men studied the stars and the other heavenly bodies, they believed that our little earth was the center of the universe—the most important thing in it and the largest. Observation of stars and planets showed them that these bodies seemed to move with reference to the earth, but they liked to believe that the earth stood still and everything else revolved around it.

But in the 15th century a Polish monk, Copernicus, by observation of the heavens came to a different conclusion. It seemed to him rather that the sun was a center and that the earth revolved around it. This idea was distasteful to the majority of people then, because they much preferred to believe that their earth was more important than the sun or anything else. There were no telescopes in Copernicus' day, and not until almost a century later were men able to discover if his ideas were correct. They found that they were correct. The earth proved to be very, very much smaller than the sun and to move around it in an immense flattened circle (ellipse). The sun is in one of the foci of this ellipse, and so the earth in following its path comes closer to the sun at one time and then gradu-

ally moves away toward the other end of the ellipse, where it reaches its greatest distance from the sun.

The sun is about 93 million miles from our earth. It takes the earth just one year to move completely around the sun. The angle at which the sun's rays strike the surface of the earth determines the intensity of the heat and light received. The axis of rotation of the earth is at such an angle that at all times one half of the side facing the sun is exposed to the comparatively direct rays of the sun, while the other half receives these rays on a slant. In other words, summer prevails on the one half while winter rules on the other. Now as the earth follows its yearly path around the sun, the inclination of the earth's axis gradually shifts; and this shift takes just six months to complete itself, after which it starts rocking back. Thus it is that July, which we in the Northern Hemisphere associate with the heat of summer, means snow and ice for the Australians; and when we are shivering in January's wintry blasts, the people south of the equator are going swimming and drinking iced tea.

In our previous chapters we talked of objects so small that it would take millions of them to make a speck large enough to see, and packed so close together that their distances apart are almost inconceivably minute. Now we ask you to go to the other extreme and consider the immense space of 93 million miles. The number can mean very little to you as it stands. Let us take a few illustrations.

Nowadays people often make trips entirely around the earth. They traverse a distance of about 24,000 miles on such a trip and consume about 60 days in

doing it. It would be necessary to make this "grand tour" nearly 4000 times to travel the distance of 93 million miles, and if a person traveled at the rate we do on earthly journeys, it would take him *650 years* to reach the sun!

You know from experience how quickly a sensation travels along the arm. If you burn your hand, it appears to you that you know of it immediately. As a matter of fact such a sensation does travel to the brain very swiftly,—about 100 feet a second. But suppose you had an arm long enough to reach the sun. If then you touched your finger to the fiery globe it would be *160 years* before the message would reach your brain and you would be conscious of the pain. Indeed, you could make a punching bag of the sun every day, secure in the knowledge that you would be dead from natural causes years before the pain sensation could reach you.

The discovery of this revolution of the earth around the sun was a shock to Man's egotism. But he was destined for further and even more shocking surprises. It was soon found that there were a number of other balls of matter also following paths around our sun. Furthermore, most of them are larger than the earth. It seems then the earth is to be considered only as a rather insignificant member of a large family.

These big brothers and sisters of the earth are known as planets. There are eight of them altogether, including the earth, and besides these there are a number of smaller bodies moving about the sun which are called minor planets. Mercury and Venus are closer to the sun than the earth, but these two planets are smaller than our own. Their paths

around the sun are smaller ellipses than ours, and consequently they get around quicker. This explains why a year on Mercury is only 88 days and on Venus 225 days. On the other hand, Neptune, which is the planet farthest from the sun, has a year equivalent to 167 of ours. So if you lived on that planet you would see less than half a year during your whole life. Neptune is nearly 3000 million miles from the sun.

As to size, the largest planet, Jupiter, is as large as 1309 Earths, and it would require almost a million and a half earths to fill up the sun itself if it were a hollow ball.

From the point of view of a man observing all this from some place far out in space, our great earth would decidedly be an unimportant part of the celestial scenery. But in spite of this disconcerting fact, we can boast that we have one child of our own who revolves merrily around us just as if there were no other stars or suns or planets in the heavens. This is the moon. As a matter of fact, it isn't a great excuse for boasting, because most of the other planets have moons too, and Saturn has ten to our one!

We think of the moon as a dead planet. Dead because it has no atmosphere like the earth, and, although the sun beats down upon it, its lack of atmosphere prevents this warmth being retained. Consequently the moon must be a desolate place. It is a bitter cold, barren ball, without animal or plant life, endlessly and hopelessly pursuing itself around an unimportant planet, in an out-of-the-way corner of an infinite universe.

The moon is very close to us, if we consider the

other distances of which we have been speaking. It is only 240,000 miles away. Also it is a small body when compared to the earth; nearly fifty moons welded together would be required to fill the earth. The moon revolves around the earth once in a month.

The moon has no light of its own, but the powerful beams of sunlight fall upon it and are reflected back to us. As the moon revolves around the earth, and the earth around the sun, we view our dark companion from different points, and, since only one-half of the moon is ever illuminated at one time, we see sometimes a full moon, sometimes a half, sometimes only a beautiful silver crescent, and sometimes none at all. These different appearances are called phases, and the time taken for the change from new moon to half, from half to full, and so on, is roughly seven days. Thus we see how our week originated. The month represents one journey of the moon around the earth, and a year one circuit of the earth about the sun.

But we have yet to account for the day. Just as in the land of atoms everything is moving, so also in the heavens motion is what "makes the world go 'round." The planets and the moons are each revolving around something else. Besides this we have learned that all of these bodies are spinning about their own axes. The time required for the earth to rotate once around is roughly 24 hours, and that is our day. If it moved faster or slower, as other planets do, the day would be of different length. Since the earth is roughly a round ball, it is clear that the sun can only illuminate one-half of this

Rudolph Lesch.

NICOLAUS COPERNICUS (1473-1543)
Polish astronomer, who first suggested that the sun is the center of our universe.

ball at one time. One half is light and the other dark, and these halves change relatively continuously. That of course is night and day, and that explains why it is night in China, on the other side of the world, when it is day here. Furthermore this rotation of the earth about its own axis causes the sun to *appear* to move over us in the opposite direction, that is, from east to west (the earth rotates from west to east). When we speak, then, of the sun rising and setting, we must always remember that it is the earth which is in a sense setting and rising.

Once in a while, on account of the peculiar paths that the earth and the moon follow, the moon comes between us and the sun. Then the sun is partially blotted out and we see the moon outlined against it as a coal-black ball. At other times the moon only gets partly in the way of the sun, and, if we look through dark glasses, the sun looks like a round piece of cheese out of which somebody has taken a bite. These occurrences we call eclipses, and small ones occur fairly frequently; although total eclipses are rather rare.

It may well be wondered how it is we know all these things about objects so extremely far away. There are two instruments which Man has invented which are chiefly responsible. One is the telescope. This instrument is an arrangement of glasses called lenses, which make an object appear nearer than it really is. We describe telescopes in terms of magnifying power. Let us say a man at 100 feet appears with the bare eye to have a height of two feet. If we view the man now through a telescope having a magnifying power of two, he will appear as if

seen at half the distance; a magnifying power of three will cause him to appear at one-third the distance, and so on. Not only the man but every part of him appears closer. Thus if the man held a printed card in his hand, at 100 feet, with the naked eye, the print could not be read. But if we used a telescope of such magnifying power that the man and the printed card appeared only five feet away, then it would be easy to read the card.

Thus with a large telescope it is possible to see the moon—240,000 miles away—as if it were only 60 miles from us.

Of more interest is the other instrument used by astronomers—the spectroscope. In the chapter on light we learned that a beam of white sunlight, if made to pass through a glass prism, is broken up into the seven primary colors of which white light is composed. The spectroscope is simply the instrument containing the prisms and lenses required for this purpose. When this was discovered, it was very natural to examine through the spectroscope other kinds of light besides white sunlight.

No doubt you have at some time seen driftwood —wood which has been floating in the sea and is soaked with salt water—burned in a fireplace, and have admired the gorgeous yellow color of the flames. This yellow color is due to the element sodium which is very plentiful in sea water. Common salt is made up of sodium and chlorine, and one can produce the yellow sodium flame by simply sprinkling some powdered salt on a fire.

If such a yellow flame is viewed through the spectroscope, instead of a beautiful rainbow of colors

including everything from the red to the violet, we see only two narrow yellow lines, close together, and at the part of the spectrum where the yellow would appear in the sun spectrum. These two lines are indeed the fingerprint of the element sodium. Any time we look at a flame and see those two lines in the proper place, we may say with absolute certainty that there is sodium in the flame.

Because of the brilliant yellow flame it gives, we can detect the presence of sodium with the naked eye. But with many other elements this is not so, and the flame in which they are burning is apparently colorless. But no matter what element we choose, if we view its flame through the spectroscope, we see certain lines (there may be many lines from one element) whose location tells us at once of the presence of that element. An element may hide itself from our unaided eyes, but it can never deceive the great Sherlock Holmes of Science—the spectroscope.

From our knowledge of atoms, we can understand why this should be. Each color corresponds to a certain wave-length of light. We know that atoms produce light because of the electrons taking jumps. In a given atom the electrons are arranged in a certain way, and if that atom is disturbed, it will be clear that those electrons will jump which are most easily pushed out of their path. So an atom disturbed or excited always sends out the same wavelengths, just as a person if excited always acts in a way peculiar to himself.

Now suppose we should set our spectroscope so as to observe the pure white light from an electric

lamp. We should see the sunlight spectrum, all the seven colors shading beautifully from one into the other. Now take a gas burner and sprinkle some salt on the flame so that it assumes the familiar yellow color. Now place this sodium flame between your spectroscope and the electric lamp, so that you view the white light *through* the yellow. What will you see? You might imagine that the yellow color in the white light spectrum would simply be made more brilliant. But that is not what happens. At the point in the yellow where the sodium lines ought to appear, we find not deeper yellow, but *no color at all,* perfect blackness. It seems that the yellow sodium flame has the ability to absorb and destroy those wave-lengths of light which it itself sends out.

This again is true of all the elements. Pass white light through their hot vapor and the emerging light has certain of its colors entirely missing; and these wave-lengths withdrawn by the vapor correspond in spectral position to the bright lines we see if we view the vapor directly with the spectroscope.

If there is a mixture of elements in the flame, there results no confusion. All the lines of all the elements appear, separated by their proper distances. Let us imagine that we have a round ball which is white hot and therefore gives pure white light. And around this ball is a sheath of hot vapor which is formed from the elements which make up the surface of the ball. When we observe this with the spectroscope, we will see our seven-color spectrum marked by many black lines. If we know what elements those black lines represent, we can plainly tell what elements compose the vapor around

the ball. Furthermore, since the vapor arose from the ball itself, we have at the same time learned what elements are in the ball.

Now that is what our sun is—a great white-hot ball, surrounded by a vapor, an atmosphere that is very hot also. When we observe sunlight then through a very delicate spectroscope, we should expect to find the seven colors crossed at various points by black lines. That is exactly what we do find. And by comparing the location of these lines with those obtained from earthly elements and earthly flames, it is possible to identify the elements in the sun. Somewhat to our surprise we find that there is but one element (named *coronium,* because of its discovery by the spectroscope in the sun's outer envelope, the corona) in the sun which is not in the earth too, although not all of our earthly elements are found in the great lantern of the world.

A number of years ago a scientist observed certain black lines in the sun's spectrum which he could not match with any known earth element. He concluded that this element was a peculiar possession of the sun, and named it "helium," meaning sun. Not long after, someone discovered an element in a rock on the earth that gave the same spectral lines as helium, and since that time we have found very large quantities of the gas. As is well known, helium is the very light, non-inflammable gas which is used for filling the big dirigibles. It strikes one as strange that an element should have been discovered on the sun, 93 million miles away, before it was found on the earth. It looks as if scientists sometimes get far-sighted, too.

CHAPTER XIII

WORLDS IN THE MAKING

We have learned, in the last chapter, about the sun and its planets, and about those strange dark hangers-on of the planets, the moons. All these taken together we call our *solar system.* Let us see what this term means.

Our old friend Isaac Newton, who got his start under the apple tree, did not stop when he showed that bodies on the earth attract each other by the force of gravitation. Newton saw no good reason why the same should not be true of bodies out in space—the stars, the planets, the suns and the moons. So with this idea men considered that the planets at their various distances from the sun ought to be attracted by the sun in the same way as objects are attracted by the earth here. But these planets are also attracted by each other. From a knowledge of the sizes of all the members of our solar system and their distances apart it was figured out, by Newton's Law of Universal Gravitation, just how the various planets, etc., ought to move because of the forces acting on them. Later on when the telescope came into use, these predictions were shown to be correct, and Newton's Law of Gravitation appears to be indeed *universal.*

But we remember that the force of attraction

between two bodies becomes less very swiftly as their distance apart increases. So although the sun, because of his tremendous weight, holds all the planets in their endless chase around him, if a heavenly body is far enough away from the sun we can predict that our great luminary would exert no pull on it at all.

Look out into the sky on a clear night. You may see the moon and if you observe just after sunset or just before sunrise, you will see one or more of our sister planets. But all the other countless twinkling points of light that go to make up the enchanting picture, are what we call stars. Some are large, others small. Many cannot be seen with the naked eye, and we have every reason to believe that even the most powerful telescopes do not reveal to us anything like the total number of stars that exist. Some of the stars are white, or yellow, others red, and still others appear bluish. This is due to the different compositions of the stars, to their sizes and ages, and to their distances from us.

Each of these stars is a sun like ours; many, if not most of them, are far larger than our sun. The nearest star to our sun is probably somewhat more than *19 million million miles.* A flash of light, traveling at the rate of 186,000 miles every second, would require more than *four years* to reach us from such a star.

Many of the stars are double, that is, made up of two stars close together. Others are triple, and so on. Each star is probably the center of a solar system like ours, with planets revolving around it, and moons around the planets. There are untold

millions of stars, and hence untold millions of solar systems. So, viewed from this standpoint, our little solar system is of far less importance than one single electron in a million tons of iron. How then must we regard our earth, which is only an unimportant member of our sun's family?

In the year 1910 the attention of people everywhere was focussed on a new and startling object that appeared in the skies—new to most people, but fully understood and expected by the men who study the stars. The thing was called Halley's Comet, and it appeared like a wondrously brilliant star with a long tail of fire. This was not the first time Halley's Comet had been seen from the earth. It appears once every seventy-six years, and may be expected again a few years before the end of the century. Originally these comets (many others have been observed beside that known as Halley's) did not belong to our solar system. They are wanderers throughout limitless space, and their origin no one ventures to explain. Somehow or other they come close enough to the sun to be attracted by that body. Then they move about the sun in a long graceful sweeping path known as a parabola, and then shoot off into the great unknown regions whence they came, never to return. But sometimes, as in the case of Halley's Comet, in their original trip around the sun they may approach closely one of the planets and be attracted somewhat by it. If things happen just right, the comet may be forced to change its path from an open parabola into a closed ellipse, and so move continuously around our solar system just as the planets do. Thus it is that

the sun and its little family may sometime capture one of these strange vagabonds from space and force it to remain with us.

Black dot represents the earth. Dotted parabolic curve shows path of a comet which enters sphere of earth's attraction, is bent around and flies off again into space, never to come near us again.

FIG. 11.

Here the comet has been "captured" by our solar system, its orbit closed into an ellipse, and it is henceforth just another planet revolving around our sun. This is what happened to Halley's Comet; it requires seventy-six years for the comet to go completely around its elliptical orbit.

As our telescopes traverse the night heavens, now and then we see what looks to be a faint cloud far

off in space. These are called *nebulæ* (from the Latin word for cloud), but it must not be imagined that they resemble our earthly rain clouds in any definite manner. These nebulæ are of various types. The most interesting are called the spiral nebulæ, and have a shape like a corkscrew. These spiral nebulæ are spinning about at terrific speeds, but are not moving through space with great velocities compared to the stars.

Much mystery surrounds these celestial ghosts. But they are of particular interest to us, because many people believe that they represent worlds in the making, that is, the first stages in the growth of solar systems like ours. For it is obvious to all that our world with its sun and planets must have had some beginning even though that beginning lies unbelievably far back down the corridors of time.

Let us see how these nebulæ may be beginnings of worlds. For some reason or other, the vaporous matter composing the nebula became hot. Then it began to cool, and with cooling came contraction, just as cooling produces decreases in volume of vapors here on the earth. As it contracted it became heavy for a given bulk, and its power to attract by gravitation became greater. Now consider a vaporous particle near the outside of the contracting nebula. The nebula is spinning about its own center because of the contraction, and the particle on the outside, because of the spinning, has a tendency to fly off in a straight line away from the nebula—just as we have observed particles of mud flying off in straight lines from the rim of a wheel which is rotating swiftly.

Finally the force pulling the particles on the outside toward the center of the mass, and the force pulling it off in a straight line, balance each other, and a ring separates from the outside of the cooling nebula. This process is repeated until several such rings are released. These rotate for a long time, and finally break up, undergo further cooling and contraction, and at last form themselves into globes which rotate around what is left of the original nebula, which is now a solid or half-liquid mass that is still very hot and makes the sun of the solar system that is being born.

It should be clearly understood that the above description is not something that we know to be true, as we know the facts about the present condition of our solar system. Nobody has ever observed a nebula form a solar system in this way, for it takes millions of years for all the changes to be gone through. We know the heavens are filled with nebulæ, some hot and spinning slowly, others cooler and spinning faster. And so it seems that it might be possible for worlds to form in this way. But other people have different ideas, and it will probably be a long time before we can say with certainty who is right. A point in favor of the nebular theory is that the planet Saturn may be seen through the telescope to have two rings encircling it; thus Saturn may be in the act of withdrawing from our family circle to form a solar system of its own.

For countless years the sun has been sending us our daily allotment of life-giving light. One is inclined to wonder where the sun gets all the energy to manufacture this light. This is another matter

on which we cannot be sure. Some suggest that stray remains of stars that have broken up (meteors) fall upon the sun with such force as to develop great heat and thereby furnish the energy required. Other ideas have to do with the high temperature of the sun causing the atoms of the chemical elements of which it is composed to break up into their electrons and central cores, with the release of the energy that the atoms are known to contain. This last idea, when combined with certain changes of size the sun probably undergoes, seems the most reasonable explanation. But after all, we do not know.

It cannot have escaped the reader that there is a most astonishing and beautiful similarity between the architecture of the smallest thing in the universe —the atom—and the largest thing in the universe—a solar system. In a certain sense every atom is a solar system. The central core—the nucleus—is the sun, and the electrons that revolve around it correspond to the planets. In the atom there are no moons for the electrons; that is one difference, and there are others. In an earlier chapter we learned that the electrons are held close to the nucleus by a force we call electricity. The nucleus has a positive charge and the electrons negative charges. So each electron is attracted by the nucleus and repelled by its fellow electrons. That causes them to move swiftly around the central core in paths which are the flattened circles with which we are familiar from our star study.

In the Solar System we call the attraction that holds the planets in their paths around the sun

gravitation, which describes the tendency of matter to run together. As we have learned, there seems to be no real difference between matter and energy, and therefore we can suggest that gravitational and electrical attraction, if not the same thing in two different dresses, are at least more closely related than appears on the surface.

Suppose we took an observer very far off into space, so that through his telescope he could just make out the outlines of our solar system. Then we might furnish him with a microscope from our imaginary laboratory so powerful that he could just see the electrons and nucleus in an atom. We may imagine that our observer in looking now through his telescope and now through his microscope would be quite unable to tell which is the solar system and which the atom, so entirely similar would they appear.

CHAPTER XIV

THE CHEMICAL FACTORY IN THE GREEN LEAF

Up to now in this book we have spoken of things which are entirely universal. First we learned that the matter of this earth is built up of combinations of ninety-one distinct elements. Later we saw how the spectroscope had revealed to us that the various other members of our Solar System, and indeed all other solar systems throughout boundless space, were composed of these same elements. It looks as if the whole Universe were made out of one batch of material, so to speak. We have nothing down here on the earth in the way of matter which we may justly boast of as our private possession; we share our substance with the Universe.

The same can be said of energy. Our chief source of energy, the sun, lies leagues off in space, and we have every reason to believe that energy takes the same forms and obeys the same laws in every corner of the Universe as it does here on our earth.

But now we must consider something which *may* be found only on the earth, and, if this is so, which makes our earth stand out in importance in the whole Universe. This thing is life—living plants and animals.

Men of all times have wondered if human beings lived on Mars or on the Moon. There is really no

way of knowing—unless some miracle should send a man of Mars here to prove it. But we know a great deal indirectly which bears on the question of life in other parts of the Universe. For example, it is generally agreed that there is no air on the Moon. It is plain then that men like us could not exist on that body. But it is not at all out of the question that other types of living beings exist on the Moon,—entirely different from us and from all plants and animals on the earth, but yet *living* things. Nobody knows and it is a question whether anyone will ever know. But in intensely hot stars like our sun we know that chemical molecules cannot exist, owing to the high temperature, and that therefore all matter is eternally separated into its atoms. This apparently means that life of any kind is impossible on the hot stars, because the bodies of living things must certainly be composed of combinations of elements.

Here on the earth we have minute forms of life—bacteria—some of which live on iron rust, others on stones of various kinds. Indeed there is scarcely any material or any condition of heat or cold (if we do not get into extremely high temperatures) but what there is some bacterium which is fitted to live there. So let us remember that, although it is very probable that living beings like us could not be found in other parts of the Universe, nevertheless it is possible that there are countless millions of heavenly bodies which are teeming with some kind of life.

Living things may be broken up into their chemical elements just as we did with the piece of coal. And we find that even such a thing as the body of a

man, so utterly different from dust and stone and water, yet contains no element which is not found in lifeless matter.

If you examine a drop of stagnant water with a microscope you will see little drops of colorless jelly. If you watch one of these drops closely you will see the thing continually changing its shape.

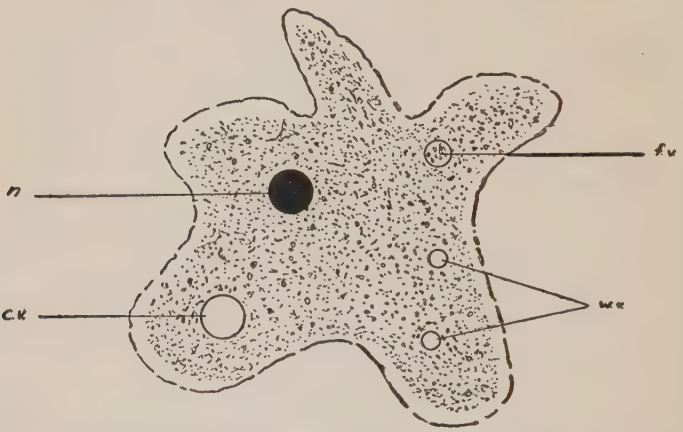


Fig. 12.—The *Amœba*. This microscopic one-celled animal is essentially a tiny globule of naked protoplasm; yet it possesses all the mechanism necessary to the restricted, although perfectly authentic, life which it leads. *n* is the nucleus; *c.v.* the contractile vacuole; *w.v.* the water vacuoles; *f.v.* the food vacuole. Its shape changes continually, so that this sketch can represent only one of the many different forms it takes during a few moments.

First it is round like a ball. Then a little swelling appears on one side, gradually becoming larger. Then you observe that the whole body—for this is a living thing—seems to flow into this little blister. It is easy to understand how this flowing of the body of the *Amœba*—for such is this tiny atom of life

called—allows it to move a little. The little blisters which appear on the side toward which the animal wants to move, are called *pseudopods,* meaning *false feet.* The Amœba is economical; it does not bother with a foot until it wants to move, and then it quickly grows one, uses it and then causes it to disappear.

The little Amœba eats as we do, and uses the food to grow and to furnish energy for moving about to get more food. When it moves with its absurd "false feet," it does so either to seize upon a food particle, or to get away from some object that threatens to harm it. In other words it moves not confusedly, but with a purpose.

We shall see shortly that this little animal, like all other living things, has the miraculous power to create other little Amœbas like itself.

If we observe in the same way through our microscope a particle of coal or stone, we will see none of these things. The particle of lifeless matter may move about, but haphazardly and without apparent purpose. It will never eat another piece of wood and will never break up into two similar particles. Thus the Amœba, silly and stupid as it is, does things which wood and stone can never do. What the Amœba does, all living things do, and what the mote of stone dust cannot do, a towering mountain cannot do. We say the Amœba has life. That is a short way of saying that this little animal eats, grows, runs away from danger and reproduces other little animals like itself. The Amœba is one of the lowest forms of life. Higher plants and animals do these things more efficiently but they do the same things

and nothing more. Only when we come to Man do we find the animal doing any thinking about it. If you poke at the Amœba with a splinter, the Amœba always runs away; if you put a bit of food near an Amœba it always eats it up. But if you punch a man with a stick, he may or may not draw away, as he wishes; if you set a dinner before him he may or may not eat, depending on how hungry he is.

Let us examine a little more closely into the division of an Amœba to form two others. First we observe that the animal is not a perfectly clear mass of jelly. Near a side is a black spot, called the nucleus, and throughout the body there are several clear spaces filled with water. When the Amœba divides, the nucleus also divides and so do all the other spots and granules. One-half of the nucleus and one-half of every granule goes into each of the daughter Amœbas. The parent has disappeared but two more have taken its place. Eventually these two divide, and so on forever. Indeed we believe that the Amœba never dies a natural death. Unless some larger animal eats it it continues its life through its children and their descendants forever.

A mass of jelly with its nucleus, its various granules and clear spaces, with its surrounding wall slightly tougher than the interior, we call a *cell.* Whenever the quality of life appears we always find it associated with a cell like this. The lump of jelly as a whole is the body; the clear jelly, the flesh; the nucleus and the granules and so on, the organs. Many animals and plants, like the Amœba, have only one cell. Others have several cells, and when we come to Man we find an animal with uncounted

millions of cells. But in animals and plants having more than one cell, these cells are not all alike. Some of them are adapted for digestion of food, others for sensing danger, and still other for reproduction. In man we have thousands of special kinds of cells. But bear in mind that the cells that make up your eye are nothing but Amœbas which have specialized in seeing just as a student specializes in medicine or law. Let us not be too quick to laugh at the silly flying about of the little Amœba, for at one stage of our lives we were one-celled animals ourselves.

A characteristic of life is the ability to reproduce its kind. In the simplest animals like the Amœba, this is done by simply splitting in two. In others the method is more complicated, and in the higher animals the process is quite involved. In these higher animals, two types are developed: the male and the female. The male produces one kind of cell and the female another. Before a new animal can be produced, the male and female cells must meet and fuse together, forming a one-celled animal. This cell then divides by splitting in two and these two divide and so on, some of the cells specializing on certain functions, some on others. Finally when the animal is fully developed, it is like its parent, and, as is not the case with Amœba, the parents still live.

It has never been possible to construct an imitation animal or plant cell out of materials which are not living, and have this cell live. People have been trying to create living creatures out of lifeless matter for hundreds of years, but nobody has ever succeeded. As we said above, we can analyze a living

cell, and find out the chemical substances which are present, and with our microscopes we can discover just how the several parts of the cell are put together. It would seem then, that if we took these materials and built them up into the shape of the cell, the resulting structure ought to live. The fact is that it does not.

This failure to create life may be caused by one of two things. Some people believe that even though we can find out what chemical elements are in the living cell, and even though we can imitate its form and shape, yet there is—they say—a mysterious something which we have not yet discovered, which is present in all living matter, and which indeed makes it live. Nobody has any suggestions as to what this magical ingredient is, other than that it may be a kind of energy which is different from all kinds that we know about, and which they call living energy.

However, still other people prefer to consider that the secret of life is not something mysterious that is too big for the mind to understand, but rather that our failure to manufacture living things is caused by our incomplete understanding of the chemistry of living matter.

The jelly-like substance which composes all cells is called *protoplasm*. To the naked eye the interior of a cell looks like perfectly clear jelly. But more careful examination discloses that the clear jelly is broken up by myriads of tiny granules, little holes filled with air or with water or with something else; by cracks and crevices and fissures of all shapes and sizes. In the same way we see a house at twilight

only as a dark bulk outlined against the sky. For all we can tell from a distance it might be cut out of smooth black cardboard. But on coming closer we find the house to be made of many dozens of different kinds of things, such as bricks, tiles, wood, glass, etc. The fine structure of the protoplasm is vastly more complicated than the most elaborate building.

For a man to attempt to construct protoplasm out of dead matter, is very much like a child trying to build a skyscraper after observing one through a telescope. Despite the fact that we have spent countless years studying protoplasm and living cells, one must confess that as yet we know very little about them. But most people whose business it is to study living matter are agreed that there is nothing more mysterious about protoplasm than the inconceivable amount of hard work necessary to understand it. They are confident that at some distant time—perhaps thousands of years hence—we shall reach a full understanding of the nature of living matter.

Life seems always to come from life. That is to say, living matter is produced by living matter. There is a legend among boys to the effect that a horse hair, if put in a water barrel, will turn into a snake. Not so many years ago, nearly everybody believed such things as that. They thought that by mumbling some magic words over a lump of dirt, it could be made to change into some living animal. Even in the last century learned societies in Europe and America spent most of their time arguing about this. One man reported that he took some perfectly pure water and kept it in a vessel for a few days,

well closed up, and on examining it later with a microscope found little living bacteria. Therefore, he said, life is continuously arising from dead material. But there lived at that time a great Frenchman, Pasteur, who could not bring himself to accept this: so he repeated the experiment of the water and the flasks, and succeeded in proving that the bacteria did not come from dead water but from other bacteria that were floating in the air. He showed that if the water was carefully freed of all air and if the glass vessels were thoroughly washed with strong acids, then no bacteria appeared even after standing for years. Pasteur devoted his life to the study of bacteria. He is chiefly known for his great work in teaching us how to prevent diseases which some bacteria cause. So great is this service that people often lose sight of the fact that Pasteur was the first definitely to prove that life always springs from previously existing life.

No doubt the reader has wondered, when we were speaking of cells and living matter, why we made no distinctions between plants and animals. Perhaps it seemed that there were two entirely different kinds of protoplasm, one for the plants and one for the animals. That is not true. There are indeed some regular differences between animal cells and plant cells, but the differences are no greater than those between certain groups of plants and of animals. It is believed that when life first appeared on this planet it was in the form of a single cell even simpler than the Amœba, which we could call neither a plant nor an animal; it was no more one than the other.

Rudolph Lesch.

Louis Pasteur (1822-1895)

French chemist, renowned for his study of the microörganisms that cause disease.

In the next chapter we shall see how from this small beginning there arose all the animals and plants that fill up the world to-day. Very far back in time when living things were still very simple, the family tree of life began gradually to separate into two branches. One branch later became the animal kingdom, the members of which lived by eating plants and their fellow animals. In order to do this it was desirable that they move about over the ground or in the air or water so as to seize their prey. The other branch became the plants which as a rule do not move but are fixed in the earth. The bark of a tree corresponds in a way to the bones of the skeleton of a man. Both the tree and the man need some sort of support for their body. But the tree, having no legs or arms to fight with, grows its skeleton on the outside for protective purposes.

This is one difference between plants and animals, but it is not a universal one because there are some animals, such as oysters and crabs, which have their shells on the outside. But the most interesting distinction between those branches of the family tree lies in the method of obtaining food. We animals are cannibals, all of us. We all eat other living things. But the plant is more refined. Disdaining cannibalism, it has developed a factory in which the raw materials are air, water and sunshine, and the product is food for the plant to grow on.

This chemical factory has a branch in every green leaf. Air is composed of oxygen, nitrogen and carbon dioxide. The green leaf absorbs carbon dioxide and water vapor, and puts them together to form sugar

and starches, from which by further changes it produces wood.

But here the insignificant little green leaf is a far better chemist than man is. Although this too has been studied for years and years, no one has ever found out how the green leaf does it. If we did know, we could manufacture many of our foodstuffs from air and water, and the high cost of living would be a thing of the past. We said above that, besides air and water, the plant makes use of sunlight in its factory. It seems to have a very highly complicated arrangement for transforming the energy of sunlight into that of chemical combination. This arrangement is quite firmly bound up with protoplasm, and it may be that we shall not solve the problem of manufacturing food from air before we have learned the secret of the living cell.

It is interesting to trace the source of the energy one obtains when he eats a bit of bread. The flour from which the bread is made comes from the wheat grain, and the wheat grain is manufactured by the wheat plant out of air, water and sunshine. The source of energy is the sun, nearly one hundred million miles away.

In the leaves of most plants there is a brilliant green dye, called *chlorophyll*. We are certain that this chlorophyll is the substance which in some way converts sunlight into useful chemical energy, but we are not sure just how it does it.

We must not leave the subject of protoplasm without remarking upon the very great importance of the common substance water, in everything that has to do with life. Protoplasm itself is about two-thirds

water, and if any considerable amount of the water in the protoplasm of the cell is removed, the cell dies. We have already seen how the water vapor which is always present in the air is one of the raw materials from which the green leaf manufactures sugars and starches.

It should be noticed that, in a certain sense, plants are closer to nature than animals. For there is no animal which can make direct use of the energy of the sun. He must eat a plant which has grown by absorbing the sun's rays. It may be objected that many animals eat other animals, but if we follow it far enough, we always find that the original energy was obtained from the sun through the medium of some plant.

There is yet another matter in which the plant makes itself absolutely necessary to man and all other animals. The bodies of animals all contain very large amounts of compounds of the element carbon. When the body of an animal does work, some of these carbon compounds are broken down into simple substances which are of no further use to the body, and which like the ashes in a locomotive firebox have to be removed or else they will clog the machinery. Animals remove a portion of these poisonous clinkers by causing them to combine with oxygen, producing the gaseous substance carbon dioxide. First of all, these waste products get into the blood, and the blood at one stage of its circulation through the body passes through the lungs, in which it is separated from the air we breathe only by very thin membranes. The oxygen of the air which the animal breathes in, diffuses through the mem-

brane into the blood and there combines with the carbon to form carbon dioxide. This gas then passes back through the membrane and is poured out into the air when we exhale.

Thus animals are continuously breathing in oxygen and breathing out carbon dioxide. There is a lot of air in the world, but there are also a great many animals. If what has been said were the whole story, it will be plain that the oxygen of the air would have long since been used up and all the animals would have died. But the plants come to our rescue. Through their leaves they take in the carbon dioxide which we have exhaled, and, besides using it to produce food, also send out a quantity of oxygen into the air. That explains why the amount of oxygen in the air is always about the same although animals are continuously using it up. It will also be clear now why large parks filled with green trees and other plants are very desirable in a crowded city.

CHAPTER XV

THE BEST MAN WINS

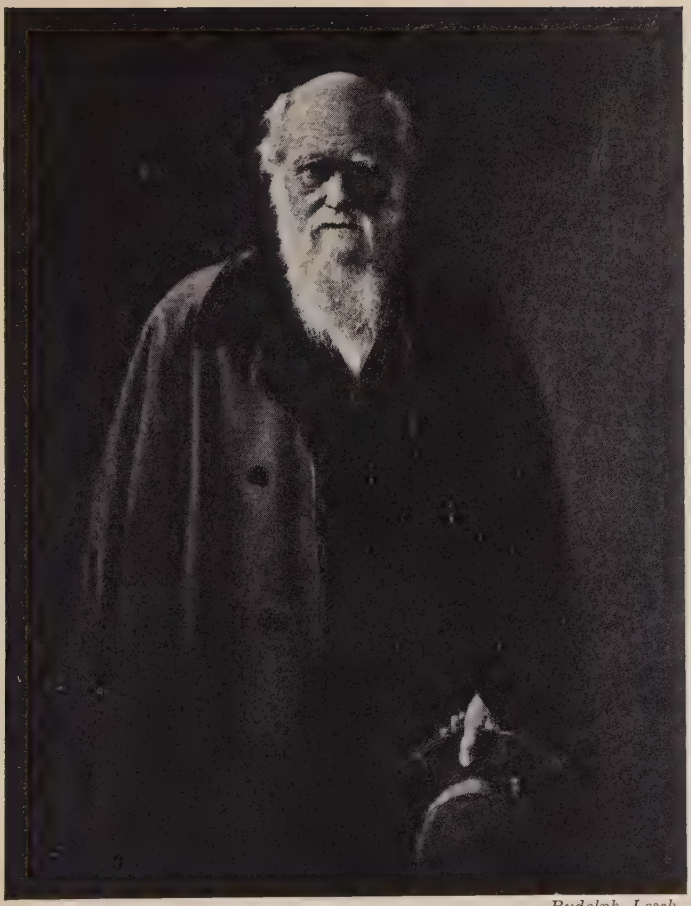
It has been stated that life first appeared in the world in the form of a one-celled being vastly simpler even than the Amœba. It is natural that the reader wonder how all the millions of different kinds of plants and animals arose from this tiny pin-point of jelly, which in a literal sense was the ancestor of us all.

Although many of the details are obscure, we can nevertheless sketch a fairly satisfactory picture of how this remarkable result came about. One of the characteristics of living things is their ability to reproduce other living things. We can then say that this first bit of living jelly split into two similar cells, which were able to eat bits of food and grow, like the first. These two cells we may describe as the children of the first. Now we know from observation among people and animals that the children are never exactly like the parents, although they always resemble them somewhat. Furthermore, the individuals in a group of brothers and sisters bear certain similarities to each other, although they are never identical. Going back to our jelly beings, we can conclude that the two children were a little different from the parents. They were also slightly different from each other. For example, one might

have been a little larger than the other, or a little more vigorous. As time goes on the two children also split up so that we have now four cells, and each one of the four is a little different from each of the others.

What we have described thus far is something that goes on in the living cell quite independent of the sort of surroundings the cell happens to be in. But to carry our picture further we must now look into the physical conditions of heat or cold, light or darkness, abundance or scarcity of food, etc. Let us suppose that two of our four cells are somewhat more active than the other two. In the place where the four cells are living there is, let us say, only enough food for two of them. There will then be a contest among the four cells for the available food. Obviously the two vigorous ones will get the most food. They will become strong and healthy and their children will be likewise, whereas the other two cells, if they do not die, will become weak and incapable of producing healthy new cells. Thus the fact of the scarcity of food caused a *natural selection* to be made of the two cells out of the four. The next generation will resemble the two vigorous parents and so a race of cells will be developed which is specialized in getting food.

Again, starting with our two children of the first living cell, let us imagine that a gust of wind came along, picked up one of the two cells and took it to a place which was considerably colder. Of the children of this cell, some will have slightly thicker outside coverings than the others. Those so protected will have a better chance of withstanding the



Rudolph Lesch.

CHARLES DARWIN (1809-1882)

First to apply the scientific method of observation and experiment to the problem of the origin of the various species of plants and animals. The modern Theory of Evolution is chiefly due to Darwin.

cold than their less fortunate brothers and sisters. They will reproduce and an increasing proportion of their children will have thick coats, because children tend to grow like their parents. Those that do not, will die off. In this way also a new race is produced which is suited to a cold climate.

To give an illustration closer to home, it is believed that the negroes in Africa are black because the black skin gives them a certain protection from the sun's rays. In the early days of the race, some individuals had darker skins than others and they consequently suffered less from the hot African sun. They lived and reproduced and among their children the majority had dark skins. The American negro, of course, is not native to this temperate climate, but was imported here in the early days of our country.

The evolution of all the different plants and animals in the world to-day from the original bit of living jelly was compared in the first chapter to the growth of a tree. The seed from which the tree sprang corresponds to the first living cell. Very early our tree of life split into two great branches which were, as we have described, the plant and animal kingdoms. Each of these two branches has now grown so long, complicated and twisted, that what we really have in the family tree is two great trees meeting at their base. In the kingdom of plants, a very large number of limbs, branches and twigs represent the vast array of distinct families of plants, with many of which we are familiar. For very obviously, plants may be divided into families, races and communities just as we may so divide people,

Thus all the mosses make up one great family which, although its members may differ widely among themselves, stands nevertheless in sharp contrast to the great family of flowering plants.

While speaking of flowering plants, it is interesting to note that while to most people flowers are objects of beauty and nothing else, to the plant itself, if for the moment we may consider it capable of thought, the flower simply is a very clever device for persuading bees and other insects to assist in bringing together male and female cells so that new plants may be produced. The flower contains a sweet liquid which attracts the bees and induces them to light on the flower in order to feast upon this liquid, which is called *nectar*. This is where the cleverness of the plant comes in. Of a group of roses, for example, some individuals produce female cells and others male cells. In order for a new rose plant to arise, it is necessary that these two kinds of cells come together. So the plant sprinkles its flower with its reproductive cells. Along comes the bee, lights on the flower for a drink of nectar, and some of the little reproductive cells stick to its body. And then when the insect goes to a flower which produces male cells, some of the pollen dust from the first flower drops off and the two kinds of cells are brought together, forming a seed from which a new rose bush may grow. In this way we have a mutually beneficial combination between the bee and the plant: the one gets food and the other is afforded a means for reproducing its kind.

In the case of the animal branch of the family tree of life, things are even more clear-cut and striking.

The real key to the understanding of the great differences between plants and animals is that at the time of the separation into two branches, members of that branch which was to become the plant kingdom invented this remarkable substance chlorophyll, which enabled them to obtain the food necessary to growth from air and sunshine. It was therefore unnecessary for them to move about in search of food or to devour other living things. But the other branch, the animals, displayed no such inventive genius and were doomed forever to live by eating their weaker brethren.

Since this time of separation of animals from plants very many changes have taken place in the surface of the earth and in climate. Each change meant different conditions of living. It meant that if the animals were to survive they must change along with the climate—and so they did. At the period of the earth's history when most of the land was covered with water, there was not enough space for all the land animals, so some of them took to the sea and developed an apparatus for filtering out air from the water for breathing purposes. They became the fishes. At another time the air seemed to offer an excellent place to live. So some of the animals began gradually to exchange their front legs for wings which enabled them to fly. As they developed further their blood became warmer than land animals, to combat the intense cold of the upper atmosphere. For the same reason their bodies became covered with feathers.

For several million years past, animals have on the average been decreasing in size. Long before

man appeared the earth was populated by enormous flying reptiles and dragons of grotesqueness beyond description. These animals, although possessed of bodies capable of effective fighting, were remarkable in the very small size of their brains. There is one whose skeleton has been discovered—to which the musical name of *Triceratops carnegei* has been given —which may be justly called the original bone-head. It is said that he had a skull eight feet thick and a brain less than four inches in diameter.

But since the time of *Triceratops* bodies have become smaller and more delicate and pleasing to look upon, and brains have become larger and more efficient and adapted for thinking. In man we find this tendency attaining its greatest height. We have lost the hairy body, the long curved claws, the horrible appearance designed to frighten the enemy, the twisting tail which aids in climbing trees; but with this loss we have gained a brain which places us in every respect, head and shoulders above all other animals.

Let us now sketch over what we have said in this chapter about evolution of animals and plants from the first living cell. First of all, we may say that there are two groups of influences working. One of these groups has to do with the environment, the physical conditions of the place where the animal or plant lives. The other is connected with the nature of protoplasm itself.

When we ask such questions as, "What makes a cell divide?" or, "Why do the divided cells resemble their parents?" then we enter into the domain of the second group of influences. Our answer to these

questions and all like them, can be brief and to the point: we do not know. To some extent we know *how* cells divide, for example; that is, we know something about the mechanics of cell division. With the microscope we can observe that when a cell splits up, the nucleus and the various granules present also split, and we can see the order in which these things occur. But when we are pinned down to the question we must frankly confess that we have no inkling as to the *reason why* these things happen. If you inquire why a man does a certain act one can answer that he does it because he wants to. That is, because he has thought it out and his mind directs him to do so. Similarly one could say that the Amœba divides because it wants to. But to say this would be to give a sort of mind to the Amœba, which one feels, to say the least, rather reluctant to do.

We can say that the one outstanding thing about protoplasm is its apparently unconquerable desire to change continuously and to diffuse itself throughout the whole world as living plants and animals. From this point of view, the individual animal or plant rapidly loses in importance; the big thing is the protoplasmic germ of life for which the individual is a temporary and inefficient carrier. Thus it has been said that the "hen is only an egg's way of laying another egg."

We may speak much more definitely and conclusively about the factors of the first group, namely, those which concern the environment or physical surroundings of life.

Let us say that the children of an animal or plant

formed from the cooling of molten lava sent out by volcanos. Stones are being formed in other ways all

FIG. 13.—*Archeopteryx pterodactyl.* Of course, no one has ever seen one of these prehistoric birds, but from skeletons that have been found we judge that he looked something like this.

the time, but at such a slow rate that we cannot perceive it. An animal dies, and if exposed to air the flesh decays away and only the skeleton is left. If

nothing happens to these bones they will eventually crumble away to dust and be lost. But sometimes the skeletons get caught in the slow rock formation or in the hot liquid rock, in such a way that they are protected from the disintegrating action of the air and the weather, and, so to speak, are sealed up in a stone. So it is that skeletons of animals that lived millions of years ago have been preserved to us in the rocks. The rocks have been deposited, not as one continuous block, but in layers caused by the different disturbances which have affected the earth. The farther down in the earth we go, the farther back do we go in time. The layers which were deposited millions of years ago are ordinarily so deep now as to be inaccessible, but unheavals of various kinds have very often thrown these lower layers to the surface where they may be examined.

By studying the skeletons obtained from successive layers of rock, we get a bird's-eye view of the life history of an animal like the horse or Man. When we find in this way a whole series of horses, each one of which is a little more developed than the preceding one and in which there are no gaps, it seems fairly certain that development took place by slow evolution from primitive forms and not by special acts of creation.

There is another line of evidence which is if possible more convincing. According to the ideas which we have set out in this chapter regarding the origin of present day plants and animals, we must believe that all animals are related to each other in the same sense as cousins are related, by similarity in the blood. For example, Man is related rather closely to

all animals that have backbones. Some time ago experiments were made in the mixing of the blood of different animals. When the blood of a man is mixed with that of an eel, a pigeon, a horse, a dog or a cat, there is no harmonious mingling of the two bloods. The bloods seem to have little in common. However, if the blood of a man is mixed with that of certain kinds of apes, they appear to mingle without protest. It seems then that blood relationship is not a figure of speech, but something very real.

We have shown how there is a natural selection of animals or plants which happen to be best suited to the environment. Very shortly after this was thoroughly understood people came to the realization that it is possible for man to intervene in evolution and vastly shorten the time necessary to bring about a desired result. Suppose, for example, that we wish to breed race horses. The desirable characteristic in a race horse is fleetness of foot, therefore the race horse breeder selects from a lot of ordinary horses a few which are a little swifter than the others. He allows these to breed and the majority of the new generation of horses will be more than ordinarily swift. From this new generation he again selects the fastest and breeds them. Continuing this he finally produces a race of horses which win for him on the track. This is termed artificial selection, in contrast to natural selection wherein the physical conditions of environment take the part of the man who is breeding horses.

In this discussion so far we have avoided a very natural question. We said that life began as a one-celled being of the utmost simplicity of form and

action. But we have said nothing of how this first one-celled animal originated. We have stated that all life comes from previous life, but if we are to say that this first cell was really the beginning then we must make it an exception to the rule. Did it come from "dead" matter? If so, how was it formed? What is the secret of the creation of protoplasm to which Man at present has no clew? This is one of the great mysteries of the world. Not knowing, the best we can do is to make a couple of thoughtful guesses at the answer, not forgetting, however, that they are but guesses. One idea is that living matter was not created on this earth but was brought to it by meteors which fell on the earth from somewhere in space. This theory, if true, isn't much help because we still require to know where the meteor got the protoplasm. Furthermore, meteors are very hot, and the protoplasm that we know of is killed by even a moderate temperature.

There is no telling how long we must wait for an answer to this question. Scientists are accumulating information very rapidly, but we still seem to be far from the goal. This much we can say: the characteristic chemical compound in protoplasm seems to be a complex substance made up of the elements carbon, hydrogen, nitrogen and oxygen. The ordinary gelatin that we eat is somewhat similar to this substance, but it is a long way from protoplasm. The difficulty about accounting for the origin of protoplasm is to imagine how this extremely fragile substance could be formed under the conditions of temperature which we know existed when the earth was young.

CHAPTER XVI

RADIUM THE MACHINE-GUN ELEMENT

Centuries ago, at the stage of history when the center of civilization, culture and power lay in Egypt, there lived and worked a group of men whom we call Alchemists. These were the forerunners of the scientists and inventors of to-day, but they differed vastly from our modern scientists both in their method of work and in the object of their labors.

Since the earliest times the substance gold has been an object of value. At once rare and beautiful, and lending itself readily to the fashioning of objects of adornment, gold has been and is still universally regarded as the symbol of wealth, power and happiness. These scientists of ancient times, the Alchemists, were not as fortunate and free as their successors are to-day. Their only source of livelihood was the bounty of kings and rulers. It was thus necessary that they engage in such work as met the favor of the king if they expected to remain in his good graces.

Even more than now, the kings of those days were greedy, selfish and conceited. They desired, more than all else, personal wealth and power. And

Rudolph Lesch.

AUREOLUS BOMBASTUS PARACELSUS (1493-1541)

A leader of the alchemists, who sought a cheap method of making gold.

because gold stood for wealth and power, they desired gold, much gold, more than could be obtained even from the richest mines.

So the Alchemists engaged in a search for gold. They understood in some degree the fact that all matter is made up of elements, and they recognized gold as one of these elements. It seemed to them that it ought to be possible in some way to change one of the baser elements, like lead, which is plentiful, into gold. For years, for centuries even, they worked on various schemes for effecting this change of lead into gold. They managed always to keep the kings interested, so that they would continue to supply money for their experiments. But their efforts towards a "get-rich-quick" scheme never met with success. Apparently, it was utterly and completely impossible to change lead into gold, or any one element into any other. Gradually, they gave up the idea and devoted themselves to studying other things more promising of success.

Fifty years ago scientists had almost forgotten the Alchemists. When they did think of them it was only to smile a little at the crudity of their methods and the absurdity of their belief that lead could be changed to gold. For the scientists of fifty years ago were quite as certain of the impossibility of such a change as the Alchemists were of its possibility. It was believed that the elements were everlastingly unalterable. It is easy to understand the grounds for this belief. It is simply that although countless thousands of experiments had been performed, no one had ever obtained the tiniest bit of gold from lead. It seemed that if it were possible, it would

have been done, and, since it had not, it was therefore an impossibility.

We have discussed elsewhere how photographic plates contain mixtures of substances which undergo permanent alterations in chemical nature when exposed to light. Since the X-rays are nothing but light rays of very short wave-lengths, it is to be expected that X-rays, although invisible to the eye, will nevertheless affect a photographic plate. We know, of course that they do, and that this is the principle of X-ray photography used by physicians.

Soon after X-rays were discovered in 1895, and their action on photographic plates was noticed, scientists became interested in the possibility that there might be other methods of producing rays that like X-rays would traverse objects impenetrable to ordinary light and affect photographic plates. The French chemist Becquerel tried various minerals and one of them happened to contain the element uranium—the heaviest element, by the way. He wrapped a photographic plate in black, light-proof paper, and, placing a piece of the uranium mineral on the paper, left it for a while in a dark drawer. On later developing the plate he found to his great surprise that the mineral had acted like X-rays in causing a chemical change to take place in the photographic plate although separated from it by heavy black paper.

It was finally shown that this curious effect was due to the uranium contained in the mineral, and, further, that it was not any compound of uranium, but the element itself—its atoms—that exhibited this strange property of *radioactivity*.

A few years later Becquerel's experiments were continued by a quiet little woman in Paris, whose husband, Prof. Pierre Curie, taught in the great French university, the Sorbonne. Madame Curie and her husband were working with a certain mineral of uranium, known as pitchblende. They found the amount of uranium contained in the mineral and they measured the intensity of the radiation from the pure uranium and then from the mineral as a whole. They were greatly puzzled to find that their figures did not check up. The radiation from the pitchblende was considerably more intense than could be explained on the basis of the uranium it contained.

Madame Curie therefore concluded that there must be present in the mineral some other element which was more radioactive even than uranium. With infinite pains she sought for the new element, and in the year 1910 was rewarded by the discovery of radium. She had to work with *150 tons* of the mineral to obtain one ounce of radium salt. But the radiation from the new element was found to be a million times more intense than that of uranium!

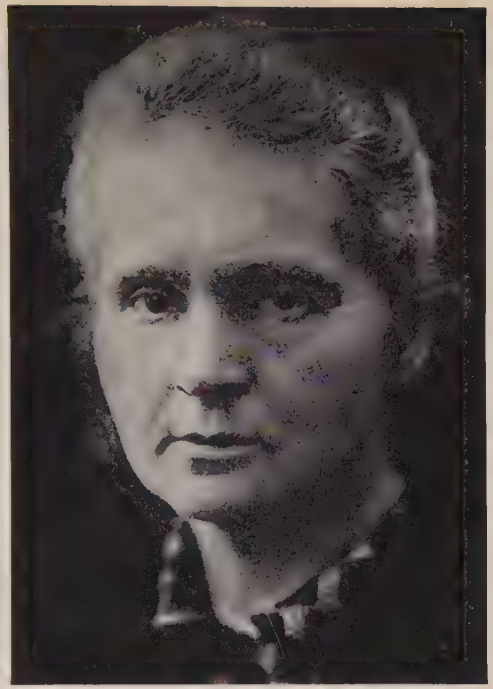
After the discovery of radium by the Curies, workers everywhere took up its study and it was presently shown that radium continuously sends out a radiation which consists of three distinct types of rays. One of them corresponds, in quality at least, to X-rays. Another was shown to be simply streams of electrons—the same electrons with which we are familiar from our discussion of the atom—which are shot out from the radium atom with a speed

nearly that of light. The radium atom is like a perpetually-operating machine gun; its bullets, atoms of electricity, are expelled in all directions with the swiftness of lightning; but the gunner, the agent that pulls the trigger of this atomic machine gun, is still a mystery, a tireless goblin who grins and leers at us and defies us to find out how his gun works.

And well he may grin, for he is doing just the thing that the Alchemists tried unsuccessfully to accomplish, and that the scientists before 1910 believed utterly impossible. For the third type of ray emitted by radium turns out to be atoms of the element helium! Here we have one element changing into another—not lead into gold, it is true, but certainly no less surprising.

But although we have here a case where one element changes into another, we have nevertheless no control whatever over the process. We cannot stop it, or start it, or in any degree change its speed. All we can do is to find uses for it and study it with a view to finding out just how it works.

Radium is chiefly useful in medicine. Sometimes tissues of the body undergo a peculiar change which, if unchecked, slowly extends through the whole body until it meets some vital organ where it causes a painful death. This is the disease called cancer. We are quite ignorant of its causes and prevention, but radium furnishes us with a valuable means for its cure. Sometimes, if caught early enough, an operation can be performed and the cancer removed, but in many cases the treatment is to sew up in the tumor a tiny tube containing radium. The rays from this substance enter the diseased tissue and



Rudolph Lesch.

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MARIE SKLODOWSKA CURIE (1867-), AND HER HUSBAND, PIERRE CURIE (1859-1906)

Polish-French physicists who discovered radium. Mme. Curie is now head of the great institute for research on radioactivity built for her in Paris by the French Government.

stimulate it to recovery. After a short time, the radium is removed and the patient in most cases gets well. Thus with the discovery of radium one of the most terrible diseases that afflict mankind found an effective remedy. The quantity of radium present in the world—extracted from its minerals, that is—is very small. It is the most difficult of all elements to extract, the handling of tons of ore being necessary for a few pinheads of radium salt. This makes the cost very great. The market price of radium varies of course, but it is usually in the neighborhood of $100 a milligram, which is a quantity just large enough to see plainly. A few years ago the women of the United States presented Madame Curie with a quantity of radium measuring about half a teaspoonful—and the cost was one million dollars! Madame Curie uses this radium for further studies on its uses and characteristics in the magnificent new laboratory which the French Government has built for her in Paris.

The rays from radium, besides affecting photographic plates, also generate heat, cause gases to become conductors of electricity, and affect certain minerals which have been exposed to them so that they shine afterward in the dark. It is on this property of radium of making gases conductive, that a simple and amazingly delicate instrument for measuring and detecting radioactivity is constructed. This instrument is the gold leaf electroscope; it consists simply of two gold leaves suspended side by side from an amber rod inside a box. Ordinarily these gold leaves lie flat against one another. But if the rod is charged with electricity—either positive

or negative—the leaves move apart in the shape of a fork, because their electric charge causes them to repel each other. They remain apart because the intervening air is not a conductor of electricity and there is no way for the charge to leak off to surrounding objects.

If now a bit of radium is brought near the electroscope with its leaves spread out, it is observed that the leaves immediately fly together. The radium radiation makes the air conductive and the electric charge of the leaves leaks off. The speed with which the gold leaves fall together measures the intensity of the radioactivity of the radium.

This instrument, simple as it is, is capable of detecting quantities of radium far too minute for any other test. If you had in your possession thirty milligrams of radium salt—a few grains—and were to divide this small quantity up so that every person at present alive in the world would have an equal portion, and if you retained one such portion for yourself, that quantity would be easily detected with the gold leaf electroscope.

These rays which radium and the other radioactive elements are continuously giving out are of course forms of energy. Relative to its size, thirty milligrams of radium salt would in the course of sixteen years give out as much as 400 times the energy that could be obtained from any other substance in the world. Radium gives out energy at a rate, relative to its mass, which no star or sun is doing.

In spite of this fact the amount of radium suffers no great change. If we started with one gram of radium, it would require 1700 years for half of it

to be used up. Uranium changes so slowly that it would take about five thousand million years for half of any given quantity to disappear.

We have no positive information as to the source of this energy which the radioactive elements are giving out. But we can make a guess which is probably correct. We picture an atom as a complex system of nucleus and revolving electrons. Each electron has energy of position—because it is pulled towards the oppositely charged nucleus—and energy of motion since it is revolving with great speed. One element differs from its nearest relative in number of electrons and in their various distances from the nucleus. It is easy, then, to see that there must be a difference of energy between two related elements.

When the goblin in the radium atom pulls the trigger an atom of helium is expelled. Helium is, next to hydrogen, the simplest element. It is four times as heavy as hydrogen, and has four electrons about its nucleus. Obviously then when radium emits helium what is left must be four units lighter than radium. We expect then to find radium changing into another element. This element has been discovered and studied. It is a gas 222 times as heavy, atom for atom, as hydrogen, and it has been named niton. It is just as much unlike radium as it could possibly be, since it is a gas like helium and argon and will not enter into combination with other elements.

The change from the element radium to the element niton causes a rearrangement of the electrons, some of the energy of position becomes energy of

motion and some of the energy of motion of the revolving electrons goes into the stream of electrons which makes up the radiation.

The energy of motion of a body depends on both its speed and its mass. The electrons making up one of the rays have very little mass; the mass of an electron is only one eighteen-hundredth of that of the lightest element, hydrogen—but its tremendous speed gives it great energy. The stream of helium atoms, although not moving so fast as the electron ray, (they go only 12,000 miles a second) nevertheless, on account of the fact that a helium atom weighs four times as much as one of hydrogen, possesses enormous energy.

If we consider the fastest bullets we fire from guns, or even the swiftest comets or meteors, and then compare their energies of motion with those of these helium atoms, we find that the latter possess a *quarter of a million* times as much energy as any other thing of which we know. It is no wonder that radium is powerful in penetrating the tissues of the body and curing diseases.

Radium gives off a helium atom and changes to niton. This gas has only a short life, a few days, and rapidly sends out another helium atom and changes to another element called radium A which is a solid. Radium A has a short life, measured in minutes, releases a helium atom and becomes another solid, radium C. In succession four other elements are produced, whose half life-period varies from one millionth of a second to about twenty years. Then finally a heavy, solid substance is produced which is 206 times as heavy as hydrogen and

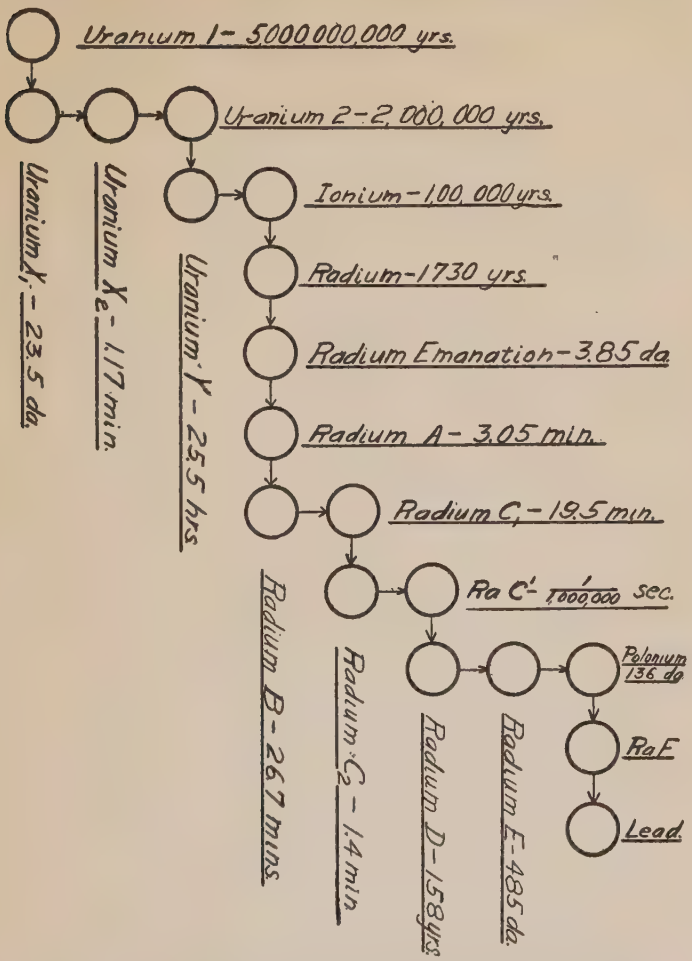

Uranium 1 - 5,000,000,000 yrs.
Uranium 2 - 2,000,000 yrs.
Uranium X2 - 1.17 min.
Uranium X1 - 23.5 da.
Ionium - 100,000 yrs.
Uranium Y - 25.5 hrs.
Radium - 1730 yrs.
Radium Emanation - 3.85 da.
Radium A - 3.05 min.
Radium C1 - 19.5 min.
Radium B - 26.7 mins.
Ra C' 1/1,000,000 sec.
Radium C2 - 1.4 min.
Radium D - 15.8 yrs.
Radium E - 4.85 da.
Polonium 136 da.
Ra F
Lead.

FIG. 14.—The Family Tree of Radium, showing it to be a descendant of uranium and a remote ancestor of common lead. Following the name of each element is the approximate time required for one-half of any given quantity to disappear owing to its radioactive disintegration into the next element in the series. The downward-pointing arrows indicate that the change is accompanied by the evolution of helium; while those pointing across the page indicate the release of electrons only.

is called radium G. We now know it to be identical with the common element lead.

Starting from the other side of radium, we find that this important element is only one of a series and we can trace it back through four other parent and grandparent elements until finally we reach uranium which seems to be the great-grandfather of them all.

Besides the uranium series, as it is called, of which radium is a member, we also know of two other series, one beginning with the element thorium and the other with actinium. In these cases also the final product of the transmutation of one element into another appears to be the common and plentiful element lead.

With the discovery of radium we have had to revise somewhat our idea of elements. We had grown to consider atoms as the very last word in stubbornness; it seemed that although everything else under the sun was undergoing continuous change, the atoms of the elements alone remained everlastingly the same. And now we find radium and its companion radioactive elements doing things that destroy utterly our faith in the permanence of atoms. Not only is one element changing into another, but a whole group of them seems to be changing around in an orderly fashion, some consuming billions of years in the process, and others requiring only a millionth of a second. What does this mean to us? Is it not possible that from these facts about radioactivity we can think out a picture of the rules and regulations in the land of atoms which is even more satisfactory than the

one previously held of utter unchangeability? Let us see.

Have you ever built houses of cards? If so, you know that the more complicated you make your house, the more cards you use, the more liable your structure is to fall over from the slightest breath of air. So it seems to be with atoms. Suppose we were building a universe of matter like the one we live in. We should attempt to construct as many different kinds of atoms as possible out of the electrons and nuclei which would be provided to us. We take a nucleus and start one electron revolving around it. Everything lovely—our structure is simple and our atom is strong and self-satisfied; we find it impossible to dislodge the electron from its orbit. This atom is hydrogen.

Now let us go further, and try two, three and more electrons about one nucleus. We have infinite possibilities for arranging these electrons, close to the nucleus, far from it, moving in circles, moving in ellipses. If we have four electrons, for example, to dispose about the nucleus, there are obviously literally millions of possible positions for them with respect to each other and to the nucleus. We try them and pick out the arrangement which gives an atom least sensible to outside disturbances. Thus we could build up the whole series of 92 elements.

It appears that the agency—whatever it was—which actually did build up our atoms did not use much thought in the matter. From the evidence at hand, he might have simply put electrons and nuclei together in *all possible* ways—not choosing the best ones—and then left it to nature and to the laws

which determine motion and electrical attraction, to weed out the best of the lot. Thus it is possible that instead of simply the 92 elements we know to-day, there might have existed at one time or another actually untold millions of different kinds of atoms, and hence of different elements. All of these, except the 92, must have had only a momentary existence, flying to pieces because of bad design, just as a bridge will give way under the first load if the engineer has been careless about calculating strains and stresses.

We can see then that out of all possible elements that can be constructed from electrons and nuclei, there are some which can exist only for an instant, and others which are so well designed that they last practically forever. These first ones we can know nothing of; they are the weak sisters of the elements, strangled at birth and destined never to achieve a place in the world of matter. But the latter group are the 92 elements which make up our present Universe. They have endured because they are best fitted for the laws which rule the conduct of matter in the Universe; in this there is a striking similarity to the survival of plants and animals because chance made them best suited to their surroundings.

There is a continuous series of possible elements, ranging from the most perfect like hydrogen and helium to those poor ghosts of elements so imperfect that they can scarcely be said to have existed at all. Plainly, there must be a borderland between the perfect elements like lead and hydrogen, and this vast region of hopeless imperfection. In this border-

land there must be elements too poorly designed to remain forever unchanged, and yet not so poorly but that they enjoy a brief period of life. Instead of exploding altogether into electrons and nuclei, they are able to put off utter dissolution by giving off only a few of their electrons and a little of their nuclei at a time. Thus groping blindly, they change themselves into other elements, hoping that by so doing they gain a better chance of survival. Sometimes they are fairly successful and endure millions of years; at other times they make bad guesses and last only a fraction of a second.

In this borderland lie the radioactive elements which we have been discussing in this chapter. Their existence has furnished us the only clew to the above picture of the origin of atoms. The picture may be wrong, but until a better one is presented, it gives us the most reasonable view of the matter.

This chapter must not be concluded without mentioning an experiment recently performed in Germany in which gold has actually been obtained from a baser metal, not lead, as it happens, but mercury. For the production of ultra-violet light for medical and experimental purposes, use is made of an apparatus known as a mercury lamp, which consists of liquid mercury and mercury vapor in a glass vessel from which all air has been removed. A high voltage electric spark is made to pass through the mercury vapor so that it becomes luminous and emits strong ultra-violet radiation.

A year or so ago one of these lamps in a German laboratory was broken and for some reason a chemical analysis was made of the mercury which was

spilled out. A distinct trace of gold was found, and it has since been shown that this gold was not originally in the mercury as an impurity but that it actually appeared during the several years the mercury lamp was in use. The explanation seems to be that the constant passage of the electricity through the vapor dislodged some electrons from the mercury atoms, transforming them into gold atoms.

It should be remarked that, although it seems that we have here an authentic case of the production of gold from mercury, the cost of the process is so great that it is far cheaper to buy the gold outright. Probably the Alchemists are lucky not to have discovered this method. When the king found out about the cost he might have chopped their heads off for making a fool of him and his money.

CHAPTER XVII

RELATIVITY AND THE STRANGE CONDUCT OF TIME AND SPACE

In the year 1905 there appeared in a German scientific journal which no one reads except college professors, a short article by a young German-born Swiss mathematician. Even those who understood the problems about which Albert Einstein was writing paid little attention to the paper, except perhaps to admire the cleverness of the author—just as we admire the masterpiece of some famous artist even though the portrait doesn't look at all like the model who sat for it.

But Professor Einstein insisted that his masterpiece was not only beautiful, but also true. The matters he dealt with were such that he had to wait 14 years for an opportunity to test out his theory. So in the year 1919, in the midst of the ending of the Great War, the British—who, be it noted, were the sworn enemies of the country in which Einstein was born—sent expensive expeditions to out-of-the-way places in South America to observe a certain eclipse which Einstein said would furnish a test of his strange theory.

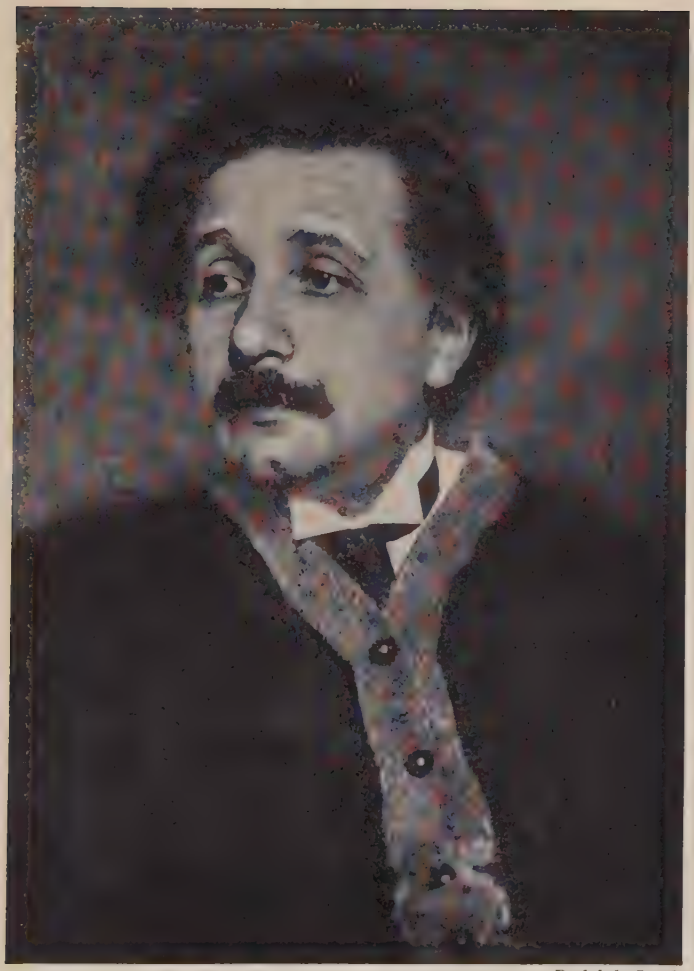
The expedition came back with results which fully supported Porfessor Einstein, and which when

announced brought Einstein's name from the little-read pages of an obscure scientific publication to the front pages of the newspapers of the world, where he shared the limelight with the Conference of Versailles. In a short time his name became a household word. His Theory of Relativity was discussed at every breakfast table, in every barber shop and street-car. Comedians at the vaudeville theaters cracked jokes about it, and ministers saw fit to mention it in their Sunday sermons.

As for Einstein himself, he was called by the German Government—though it was poverty-stricken from the War—from his small post at the University of Zürich, Switzerland, to Berlin, where he was furnished with a new laboratory built to his own specifications and with a fat salary, and where all he had to do was to sit and think. He was invited all over the world to give lectures; he became the idol of the hour. When he arrived in New York for a lecture tour newspaper reporters and photographers fought with each other for his favor; millionaires hounded him with invitations and learned societies vied for the honor of entertaining him. The commotion he created places him in a class with the Prince of Wales and the Queen of Rumania.

At the same time it was reported on reliable authority that Einstein said there were only twelve people in the whole world who understood his theory! The mathematical reasoning was so complicated that it took a genius in that subject to follow it.

How then are we to account for the great furore which the Theory of Relativity has caused? If



Rudolph Lesch.

ALBERT EINSTEIN (1874-)
Founder of the Theory of Relativity.

people did not understand it, why were they so wildly interested in it?

The answer is that although we cannot follow Einstein through all the mathematical mazes by which he arrived at his remarkable results, we can nevertheless look those results square in the face and get a glimmering of what they mean to the intelligent person who is interested in the big things before the human mind.

Let us then have a look at the facts in the case. Perhaps you have had the experience of sitting in a railway train in the station, waiting for the train to pull out. You glance out of the window and are interested to see that your train is moving; it is slowly slipping past the train on the next track, which is all you can see from your window. That is all right—until a friend walks up to tell you good-by and assures you that your train does not leave for five minutes. In confusion you again look out of the window and find that the other train is the one that is moving while yours is standing still. You can tell now because the last car of the train is now moving past you and you can see the ground and parts of the station. You observe that your train is motionless with reference to the ground, while the other train is moving when so considered.

So you laugh at your mistake. You think yourself foolish not to have figured out the correct answer at the beginning. But were you so foolish? Suppose that all you could see—as was the case at first—was your own train and the one on the other track. You see that either your train or the other is moving. Now the dining car is opposite you, and

now a sleeping car. Something must be moving—common-sense tells you that. But how can you tell if it is your train or the other that is in motion, or indeed if both are not in motion? Think it over, and try it out at the first opportunity.

But we can give you the answer now, for such experiments have been tried hundreds of times, always with the same result. There is no way to tell which is moving—unless you can at the same time see some third object which you know to be stationary and to which you can compare in succession the motion of your train and the one on the opposite track. Lacking such a stationary reference object, all we can say is that the two trains are moving with reference to each other.

It may occur to you that in the case we are discussing we can employ as reference object, instead of the ground, or the station, the air. If your train is the one that is moving then it must be moving past the air, which, provided there is no wind, may be regarded as stationary. If, however, the doors happen to be closed, then instead of detecting air whizzing through the car, we would discover by suitable experiments that air is being carried along with the car.

Let us imagine that experiments were made in your car to determine, first, whether air is being carried along with the car. You find that it is not.

You go with confidence then to the second experiment, because, you reason, air is either being carried along with us, or else we are passing through the air. If the test were actually made, you would of course find that your train is indeed moving with

reference to the air,—if it *is* your train which is moving.

But, for argument's sake, let us say that the second experiment also turned out negatively. Air is not moving through the car, and the car is not moving through the air. The answer, you would say, is easy. Your train is not moving.

Good enough—but suppose the same experiments were performed in the other train, and *with the same result!* The man in the other train would come to the same conclusion as you did, namely that his train is not moving. But when you compare notes with him, you are liable to give up the argument in some confusion, because both you and the other man will swear that one of the trains was slowly slipping past the other at the time the experiments were made.

The trains are undoubtedly moving with reference to each other. The air is still. Yet neither train is moving with reference to the air. There is something wrong somewhere. These results are nonsense. What is the answer?

There is only one answer. If the results we obtained are nonsense, then the questions we asked when we made the experiments were also nonsense. It must be that we are experimenting with something which doesn't exist. We conclude then that the air does not exist.

And we conclude also, from these experiments, that it is entirely meaningless to speak of one train or the other moving. Motion, it seems, cannot be said to belong to one single object. The two trains are moving with reference to—that is, *relative to*—

each other, and that's absolutely all we have any right to say about it.

Now in the case of the trains and the air, it would be impossible to obtain such results as we have outlined. For we know from many other experiments that the air does exist; we have direct evidence of the existence of air molecules. So our experiments could not turn out thus contradictorily.

But Einstein was not dealing with trains and air. He was dealing with the motion of stars and planets. And instead of air he was thinking of that interesting "substance" called the ether, which we touched on in the chapter on light. Viewed from the earth, the sun seems to move across the sky every day. Viewed from the sun, the earth would seem to move across the sky—but at a different rate, because the sun rotates about its axis at a different speed from the earth. Which is right? In ancient times, we thought the earth stood still and the sun moved. A few hundred years ago Copernicus came out with the idea that it was the other way around—the sun stood still and the earth revolved. We believed that and we thought it silly and egotistical to have believed the other way. But since Einstein we have to admit that one is just as wrong as the other,—that strictly speaking the only thing we can say is that the earth and sun execute a kind of motion in curved paths *relative to* each other.

How did Einstein kill the ether? He did it, as we said earlier, by ignoring it in his Theory. But the thing started, we are proud to state, by something that was done in America many years ago by two American scientists, Michelson and Morley. They

said that, according to the ether theory, light energy is transmitted through the ether. They reasoned that if the light wave has to buck an "ether wind" such as would be set up if the earth were whizzing through the ether, it would go more slowly than if the light wave were traveling with the "ether wind."

This is known to be true for sound waves in air. By simple experiments it can easily be shown that if a sound wave is traveling against a strong wind its speed, relative to the ground, is very much reduced. According to the ether theory, the ether corresponds for radiation to the air through which sound is transmitted, and it appears perfectly reasonable to expect a similar effect.

So Michelson and Morley rigged up a very clever experiment to test this out—and they got negative results. That is, their experiment seemed to show that the earth is not moving through the ether, and that the ether is not moving past the earth—and yet the earth is moving relative to the sun, for example. Now the ether theory demands that ether must be everywhere in the universe—around the earth as well as the sun. Thus the Michelson-Morley experiment is very similar to our imagined train experiment. The answer is nonsense, and we have to conclude that the question was nonsensical. That is to say, the ether doesn't exist.

This was almost a death blow to the ether. But most scientists ignored this and went right on using the concept, because they could think of nothing to replace it. But the Theory of Relativity now replaces it in an unexpected manner, not by putting

something else in its place, but by accounting for things without its use.

The famous Dutch scientist, Lorentz, suggested that the negative results of the Michelson-Morley experiment could be explained by saying that the instruments used in the experiment for measuring distances underwent a slight shrinkage when they were turned in the direction of the earth's motion through space. It would take us too far afield to go fully into this, but it must be stated that it was an idea that could not in any way be tested out, for if everything shrunk when turned in a certain direction, then the measuring rods would shrink too and there would be nothing to detect the shrinkage.

But Einstein liked the idea and carried it much farther and made it a part of his Theory of Relativity. He says that objects moving with high speeds suffer a decrease in length in proportion to the nearness of their speed to the speed of light—186,000 miles a second. The nearer they approach to that speed, the shorter they get, until, if they could be made to move with the speed of light, they would shrink to nothing. From this it can be reasoned that the velocity of light is the highest speed that any object in the Universe can attain. A length cannot be less than nothing.

Not only length but weight also changes with speed, according to Einstein. If a bullet goes with a speed nearly that of light it becomes very heavy. Its weight increases the faster it goes. Moving with the velocity of light the bullet becomes infinitely heavy.

The reader must not jump at the conclusion that

fat ladies who are trying to reduce should avoid trains and automobiles and stick to the horse and buggy. We must clearly understand that an object must be moving with a very high speed indeed before the change in size or in weight, due to the "relativity correction," becomes of importance or indeed becomes detectable. The only instances we have at our disposal for experiment are the particles that are shot from radium and the other radioactive ele-

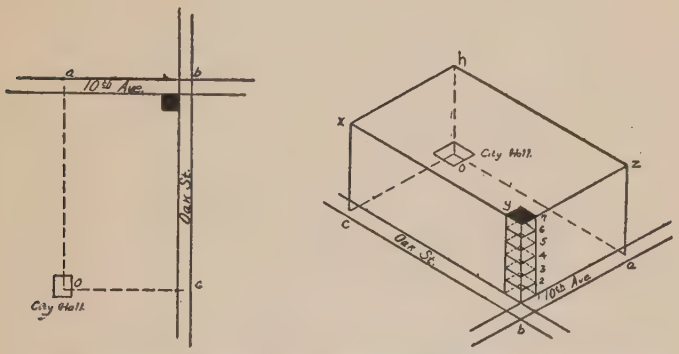


Fig. 15.—Simple Coördinate Systems. A house (black square) can be located, as shown in left-hand figure, by choosing some point of reference, as the City Hall. The house is at the intersection of two straight lines (10th avenue and Oak street), whose shortest distances from the City Hall (dotted lines *oa* and *oc*, respectively) give a complete description of the house *b* in two dimensions. On the right, where we attempt to draw a three-dimensional coördinate system, the picture has to be drawn distorted, or "in perspective," because of the two-dimensional nature of the sheet of paper. The line *oh* has a direction straight up from the City Hall and represents the third dimension. If *oh* is taken to indicate the height of seven floors, then the plane *h-x-y-z* cuts all buildings in that section at the seventh floor. The apartment in question is then located completely, as far as ordinary space is concerned, by giving three *coördinates, oc, ob, and oh;* or, what amounts to the same thing, 10th Avenue, Oak Street, and Seventh Avenue. It is impossible to make a graphic representation of the fourth dimension in this manner.

ments, which, as you remember, move with very high velocities. Einstein's Theory is just beginning to be applied to the study of these elements.

From the school-day study of graphs in algebra, we are more or less familiar with the idea of coördinate systems. We use such systems every day in ordinary conversation, without perhaps recognizing them as such. For example, you say you live on the southeast corner of Oak Street and 10th Avenue. If you said you lived on Oak Street, that would be indefinite, because Oak is a long street and you might live anywhere on it. The same thing might be true if you gave your address as 10th Avenue. But if you say the *corner* of Oak and 10th, then it is definite, because the two streets are straight and there is only one place where they meet and that is where you live.

Again, if you live in a tall apartment building, you have to add more to your address. You must say, for example, that your apartment is on the seventh floor.

So, in order to locate your place of residence so that there will be no possibility of confusion you must state three facts: something about Oak Street, something about 10th Avenue, and something about distance up from the street level.

In graphs we call these three facts the three coördinates, or *dimensions*. Your description of your location is said to be in terms of three dimensions.

All objects with which we have to do in the world have three dimensions, length, breadth, and thickness. Sometimes one of the dimensions may be

reduced to a very small value, such as in a thin sheet of paper which has length and breadth but very little thickness. But it will be plain that all objects must have three dimensions because the molecules and atoms of which they are built up have three dimensions. Oil films just one molecule in thickness have been obtained, and these represent the nearest approach to a two-dimensional object we can obtain.

If it is agreed that we can have no less than three dimensions, we have yet to answer the question as to whether or not it is possible to have *more* than three dimensions. We can imagine a point which has no dimension, although it can never be realized actually. Let this point move in any direction, and it produces a line—a body of one dimension, still imaginary. Let the line move, and we have a closed figure like a square—a figure of two dimensions, but also imaginary. Now consider that the square moves upwards from the paper on which its picture is drawn, and it generates a cube, a solid of three dimensions, an object which is real and not imaginary.

Going along in this way, it might be said that the cube could move in some certain manner and generate a body of four dimensions. There is no limit to the number of dimensions we may consider to be produced in this way. But it so happens that even a four-dimensional figure is something of which the human mind can form no picture. We can see a cube in our mind's eye, but we can form no image of a figure of four dimensions.

But Einstein says that four dimensions are nec-

essary for a complete description of an event. He is talking, however, about *events,* and not about places. He says that events are the real units in which we must describe things in the universe and that simple locations are incomplete. Coming back to your residence, suppose an explosion took place in your laboratory there, and you were giving a description, how would you proceed so that this explosion would be completely identified? First, of course, you would give your address, seventh floor, Oak and 10th—three dimensions. But then someone asks what *time* it occurred. You say at 4:15 P. M., July 10, 1926. Without this *fourth dimension of time* the explosion you are describing might possibly be confused with one that took place there at some other time. But since the same thing cannot happen twice in the same place *at the same time,* by giving the time of the occurrence you completely avoid any possibility of confusion.

Perhaps the most difficult thing about Einstein's Theory to see clearly is his idea of time. We have been brought up to look upon time as a mysterious quality which we all admit and use but which does not bear thinking about too hard. "Backward, turn backward, O Time in thy flight," was the poet's plea, but nobody took him seriously or imagined for one moment that any sensible person would think of time turning backward or doing anything else but flowing evenly forward.

In school we are taught that it is absurd and foolish to try to add together in arithmetic, five apples and eighteen miles, for example. Apples and miles are different things and are not to be considered as

having any qualities in common which would permit of their being added together. So we used to think about time. It seemed just as nonsensical to add 25 seconds to 50 feet.

But Einstein says we are wrong about this. According to him time as the fourth dimension for describing events is no more different from length than length is from breadth or from thickness. True we cannot add seconds and feet, but Einstein would have us believe that it is possible to express both length and time in some common units so that they can be added together. He calls our attention to the fact that in such a description as our explosion, leaving out the Oak Street, or the 10th Avenue, or the seventh floor, causes the same sort of confusion as leaving out the time of the event.

Einstein has discovered no way to make time go backward—probably he has never tried—but he considers that for purposes of his theory and his calculations he is justified in so regarding time. Furthermore, he believes that the world which he describes in this way is the "real" world, while the other is as false as the image we see of ourselves in a cracked mirror.

What was Einstein after, anyway? What did he mean when he said that Relativity describes the "real" world, and that our previously held ideas had to do with things which were "unreal"? What does he mean by the term "real"?

Consider, with Einstein, a straight line drawn on a sheet of paper. Is it "real"? * Einstein says no, because it is possible to crumple up the sheet of

* More accurately: Is its *straightness* "real"?

paper so that the line now exhibits many curves and bends and kinks; it is no longer a straight line. The same thing will clearly be true if we start with a curved line, or with any sort of line whatever. If the space through which the line is drawn happens to be "crumpled up" for some observer, this observer will see the line altogether differently from the one who drew it in his uncrumpled space.

This is rather a disturbing thing to learn. For all the material objects in the universe—as we see them —are bounded by curved or straight lines. But, according to Einstein, such objects have no reality! Are we living in a dream-world after all?

It will be easy to show, however, to our own satisfaction that Einstein's reasoning has sense to it. There is before me as I write a long table. If one should ask me the shape of this table, I should ordinarily reply without hesitation that its top was rectangular. But have I any right to say this? From where I am sitting I see the top of the table from a slanting position; an angle at one of the corners is nearest my eye and I am compelled to admit that, from where I am sitting, that corner is much the largest portion of the table, and the top looks far more like a figure with different angles at every corner than a rectangle with four right angles. If my eye were immediately over the center of the table it would indeed appear rectangular. But what right have I to consider that this observation post is any more justified by "reality" than the one in which I am now sitting?

The Theory of Relativity says I have no justifica-

tion at all. It says that one observation post is no more correct than another. From this we are bound to conclude that the shape of the table top is no more rectangular than it is trapezoidal. In fact we are compelled to admit that, from Einstein's point of view, the table top has no "reality"; that is, no shape.

What then *is* "real"? According to Einstein nothing is real except what appears the same to every possible observer, wherever and however situated in space and in time. Plainly our table top looks different from every place we view it; it is therefore unreal, as far as shape goes.

Coming back to our illustration of the line on the sheet of paper, which we said was not "real," let us draw several other lines on the same sheet, in such directions that the lines cross each other. Now if we try crumpling up the paper we find that while we can alter the distances between the points where the lines cross, no amount of crumpling can change the *order* in which the intersections occur. If when the sheet was flat we numbered the crossing points, 1, 2, 3, etc., we find that the order is never changed by crumpling the paper. The order never becomes 2-1-4-3, or anything other than 1-2-3-4 as it was in the beginning.

This is equivalent to saying that no matter from what point we view the intersecting lines, although the shapes of the lines and the distances between the intersections may change, the *ordering* of the intersections is always the same.

Here at last we have something that even Einstein

will admit to be "real"—not the lines nor even the places where they cross—but the *ordering* of the crossings.

Now in four-dimensional space-time, crossings of lines represent events or happenings. So, carrying this illustration from the two-dimensional sheet of paper over to the space-time continuum, we reach the conclusion that the *order in which things occur* in space-time is real, and that nothing else is.

This is rather a difficult thing to see, and common-sense is certainly opposed to this idea of reality. However, if we listen to common-sense, we run into many pitfalls, such as in the illustration of the shape of the table. So a great many of us are inclined to accept Einstein's idea at its face value, even though we are not numbered among the Twelve who understand Relativity, and cannot check up on his method of reaching these results.

At any rate, we can say that it looks as if Einstein's Theory is going to be the accepted one and that in a few years we will have it taught to us in school just as we learn the "common-sense" picture now.

Einstein's Theory is not concerned with the explanation and the description of a small portion of the matter with which Science deals. With Einstein it is all or nothing; the sky is not even the limit. He says that if his theory is true at all it must explain the whole Universe, and if there are any other universes floating around anywhere it must explain them too.

The one bugbear of previous theories which attempted to explain the physical Universe has been

the existence of gravitation. When you think of it cold-bloodedly, it is really a remarkable idea that bodies of matter if released suffer an impulse to fly towards each other with ever-increasing speed. Why this impulse? And how can we account for the fact that it takes no time for gravitation to act?

Einstein saw that if his Theory was to hold water it must explain gravitation. So he devoted much time and thought to the task.

He has succeeded in a very interesting manner, which, however, we cannot accept without giving up some other old-fashioned ideas on which we have been brought up. According to Einstein space is warped or crumpled up in the neighborhood of matter, and the greater the amount of matter the greater the crumpling up. This disturbs us because it is hard to think of a formless thing like space suffering any distortion. Let us take an illustration.

Suppose that on the tightly stretched head of a drum a checker-board is printed, the lines being, of course, all parallel or perpendicular and the squares all of equal size. If a row of worms started out together at one side of the checker-board and crawled across, they would keep together—that is, side by side—all the way. But suppose that a heavy object like a lead bullet were laid in the center of the drum-head. The rubber sags and stretches, most at the middle and least around the edges. The lines are no longer parallel and perpendicular but make various angles with one another depending upon how near they are to the center. And the squares are now unequal in size and distorted in shape. Now if the worms started across they would not keep together,

for the ones which traveled on lines passing near the center would have to follow the sag in the drumhead and on account of the stretching of the rubber would have to crawl farther to cover the same distance as before.

If we looked at this worm-race with eyes which could not see the sag in the drumhead because it lay in the third dimension, it would seem to us that the worms near the center experienced an "impulse" which drew them toward the lead bullet. That is what gravitation is—according to our former way of thinking—an "impulse" which bodies experience, drawing them together, and which increases in intensity the closer the bodies are together.

From the worm experiment we see that the "impulse" results from a distortion—a crumpling up —of the space around the heavy body of matter.

Einstein says that gravitation results in a somewhat similar manner from the crumpling up of space in the neighborhood of matter so that space becomes "bent" and the shortest distance between two points is no longer a straight line but a curved one. We cannot detect this distorted condition of space, however, because it is a part of Einstein's idea that the warping takes place in a fifth dimension, and we cannot even see the fourth in our mind's eye.

Light is known to travel in straight lines, but Einstein predicted that if his theory of the bending of space near heavy masses was true, then light rays passing near the sun or other heavy celestial body, would appear to be affected by gravitation and would traverse a curved path. This appeared to be a reasonable test and it was the eclipse expedition of

1919 that confirmed Einstein's prediction of the "bending of light."

In concluding this chapter it must be again remarked that although Einstein's Theory of Relativity gives us an entirely new picture of the Universe—and, if considered from the proper point of view, a remarkably simple one—it has little effect on the practical things of life, or even on the experiments which go on in the world's scientific laboratories. It deals with velocities approaching those of light, and if we except the radiations from radioactive elements, we know of but few cases where it may be applied.

CHAPTER XVII

CONCLUSION—HOW NEAR ARE WE TO AN UNDERSTANDING OF THE WORLD?

Our plan has been to tell the reader a few of the things we know about the world we live in. Compared to the total amount of knowledge which has been discovered and which could be outlined if we had the time and the space, what we have said in this book is very little indeed. And compared to the things we do not know about the world we live in, this total amount of knowledge is smaller still. In almost every chapter we have had to leave important and interesting questions altogether unanswered, and our excuse has been that we simply did not know.

To very many people this has seemed a most discouraging fact. To them it appeared that each new discovery we made, instead of clearing the field a little and making the whole thing simpler to contemplate, served only to open up vast new problems whose existence was previously unknown. Like a shadow the final goal was always a little ahead of us and seemed never to allow us to gain on it. It was a will-o'-the-wisp that lured us on but could not be overtaken.

The question which arose in men's minds was this: Were we really getting anywhere in this search for

knowledge? Were we justified in considering that the total amount of knowledge was a definite thing, and that if we worked long enough and hard enough and if our children and our children's children continued to work hard enough, we might hope at some distant day fully and completely to understand the Universe?

In the latter part of the 18th century a great German thinker, Immanuel Kant, lived and wrote. One of his books was called the "Critique of Pure Reason." It is a work which should be read by every person. But for most of us it must be reserved for the calm years of old age, for there is probably no book in any language which is so difficult to read and to understand as this great work of Kant's.

Just as we cannot follow Einstein through the labyrinthine mathematical approaches to the Relativity Theory, so also must the study of the written records which Kant has left be assigned to the professional philosopher. But in the latter case, no less than in the former, one can acquire thus at second hand some conception of what this amazing little German professor had to convey.

Kant in his "Critique" considered this question we raised above. And he reached a conclusion which is of great interest to us. It was his belief that the human mind can never hope to be in possession of all knowledge. He says that beyond all things which it is possible for the human mind to know and understand, there will forever be a limitless expanse of knowledge into which—as into the famed Forbidden City of Tibet—we may never enter. He considers that the human mind is by its nature thus

limited in the things which it is able to comprehend. Therefore our continued search after pure knowledge is a hopeless quest, destined never to succeed, because the things which we can understand are as nothing compared to this vast realm of the unknowable.

This is one side of the argument. There is another side which to many people is more convincing than the first. Remember that there is no way to prove the correctness of one or the other viewpoint. We have simply to accept the view which seems to our minds the more reasonable.

Suppose that, knowing nothing of the size of the United States, a man sets out to make a careful study of the geography of the whole country—every river, creek and lake, every hill and valley. After working enthusiastically for a long time it is probable that he would begin to become discouraged. It would seem to him that he was making no progress. Each time he reached, after arduous struggle, some distant mountain range, he found that instead of this range marking the end of his task, there stretched out beyond it hundreds of miles of territory that had yet to be explored. Presently he would perhaps reach the conclusion that this was going to continue forever, that there was some strange limitation in his capacity for studying geography that made it impossible for him ever to reach the other side of the United States, that if he should continue his work even for unnumbered years he would still, on wearily ascending a high mountain, find a limitless expanse of the unknown before him.

But you and I, with our present knowledge of

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IMMANUEL KANT (1724-1804)
German philosopher.

the large but definite size of our country, can realize the error which this man would have committed, should he thus have ceased his appointed task in discouragement.

This, then, is the other side of the argument. It seems at least possible that the total amount of knowledge is in reality definite and that we are making real progress. If this is true we can say that every problem solved is a true step forward, and that eventually—it may be millions of years hence—we shall reach our goal of complete knowledge.

It may be that Kant was right when he stated that the mind was naturally limited in its understanding, and that it would be too weak to contemplate the full knowledge of which we are speaking. But it may be suggested that in the world of plants and animals evolution is continually altering these living things. It is reasonable to hope that the human intellect itself, as it passes through generations and generations of men and women, is becoming stronger and more powerful, and that when the time comes for complete knowledge evolution will have kept abreast and the mind will be able to comprehend the knowledge which will reward its struggle.

In the world to-day there are many thousands of men and women who are devoting their lives to the discovery of new things, to the increasing of knowledge. We do not refer here to those who invent things to make life more comfortable or to make money. There are others whose work does not concern things of this type, and who, far from making money, are often denied the bare necessities of life.

The additions they make to knowledge have often no practical application, yet they are perhaps happier than the inventors mentioned above. Their happiness comes from achievement with the mind.

Workers of this type—and to these is due by far most of the knowledge we have discussed in this book—would have difficulty in justifying the devotion of their lives to the quest for pure knowledge, if they believed with Kant that the mind could never hope to reach its goal. And so many of them are inclined to the view that knowledge is definite and will ultimately be wholly in our possession and that Kant's realm of the unknowable was a bad dream which has no reality.

The solid, tangible world appears to our senses to consist of matter which is accompanied by different types and quantities of this elusive quality we call energy. This matter moves about and executes the various changes in shape and form with which we are familiar, in space and in some sense to the accompaniment of time.

In an earlier chapter we showed how matter and energy seem to be identical, how when the atom is analyzed it appears to consist of electrons chiefly, which are energy.

Einstein has shown us how space and time must perhaps be fused together into a single idea and not be considered separately. For want of a better name we may call this single idea "space-time," or, as in the mathematical books, the "space-time continuum."

So it would appear that the world consists, instead of the four elements matter-energy-space-time,

of the two elements, energy and space-time. Naturally, this greatly simplifies things, although the simplification seems to be obscured at first by the complexity of arriving at these results.

The last few paragraphs summarize what we know —or what we think we know—about this particular beautiful garden wherein we find ourselves. This knowledge gives us a picture of the nature of things which is sketchy and bristles with gaps and inconsistencies. But there stands out from among the host of minor faults in our picture one single glaring element of incompleteness; it stands there, gaunt and stark, pointing at our philosophers and scientists a taunting, jeering finger. "You have, by all your work," this terrible accuser says, "succeeded in linking—or in giving promise of linking—all facts about the Universe into one self-consistent chain, slender, fragile, yet infinitely strong because it is true, because Cause and Effect follow each other in blendful alteration. But do you not see, with all your wisdom, that there is a crushing fallacy in your method, a formlessness in your plan, which fates your beautiful chain to an eternity of incompleteness and dims the luster of your mighty effort with the gray pallor of futility? Do you not see that your chain has no beginning, no end; that it is but a section, a fragment of the Absolute Truth which you seek? Does it not discourage you to consider that the one truly insurmountable portion of your self-appointed task of understanding is the discovery of a First Cause to which your chain may be anchored?"

And this relentless accuser has reason in his talk. For science and philosophy function by weaving the

facts which we discover into such a chain of Cause and Effect. We consider a phenomenon to be "explained" when we have identified it as the effect of a previously established cause. And at an earlier period this which is now the cause was an effect which had to be related to some cause even farther back. And thus it goes *ad infinitum;* the chain of Cause and Effect extends sinuously back until it runs into an effect which cannot be further linked to an earlier cause. This spectral earliest cause of all, for which the penetrating mind most keenly feels the need, is what is meant by the First Cause. It continuously eludes us; it seems quite without the appointed province of our comprehension. For the existence of a First Cause implies a concept so harmonious, brilliant, and all-sufficient, that even the strictest logician would not feel compelled to look farther back and ask, "But what caused this?"

Let us illustrate. We observe that when the elements hydrogen and oxygen unite there is never less than one part by weight of hydrogen to eight parts of oxygen. The chemist "explains" this by stating that the atom of hydrogen is indivisible and weighs one-eighth as much as the atom of oxygen. Thus he gives a cause for this observation which we call the effect. But if we suggest that farther back in the chain this cause must have a parent cause of its own, if we ask, in other words, just why it is that the atom cannot be divided and still be an atom, then our chemist throws up his hands. "You can't expect me to go into First Causes. An atom has this characteristic because it has it, and that's all there is to it." In other words, he admits that he cannot

say why it is that an atom is indivisible. The characteristics of an atom constitute an effect of whose cause we have no inkling.

We run into First Causes whenever we try to trace out the logical thread in any department of science. Evolution, which admirably accounts for the development of the innumerable different forms of plants and animals, fails to stand up under the inexorable application of the logician's probe. There must have been some first particle of living matter from which all vital beings came. Where did this original first particle come from? If we answer that it developed in some unknown way from inorganic matter, then we eventually reach the point where we require to know where the first bit of inorganic matter came from. And this we cannot answer. It is a First Cause. Incidentally, we have no clew whatever to *why* evolution takes place. The Theory of Organic Evolution is narrower and more innocent than many would have us believe. It simply states concisely the results of observation of facts and makes no attempt to assign causes or delve into purposes.

To a large portion of the population of the world the phrase "First Cause" is synonymous with God. God is *The First Cause.* It is convenient thus to personify an abstruse complex need, and it greatly helps some of us to endow the personification with the æsthetic qualities we consider should be associated with infinite power. The great need in the religioso-scientific borderland is to decide whether God is really simply a synonym for First Cause, in the sense of the phrase discussed here, or whether He

is an entity actually meriting personification and clothed in reality with all these æsthetic attributes in which He appears to the Church.

Is there any hope to be held out for Intellect in its bitter struggle with the Nature of Things? In glancing over the high spots of contemporary scientific conclusions, the writer thinks he does see a gleam of hope. Mind is not infinite, and there are some situations which we may describe in words, but of which the mind cannot actually think. Such an "inconceivable concept" would be a type of matter which was infinitely divisible or continuous. If we present to the mind a description of matter as made up of finite, discrete particles—atoms—this description arouses a definite picture in the mind, for the mental faculty is so arranged that it deals with units, individuals. But if we say to the mind, "Matter is continuously divisible; it makes no difference how far we go towards dividing up matter we will never reach an end," then the picture which results is blurred, indefinite and incomplete, and would prove to us that the intellect was not adapted to the understanding of matter.

But the fact is, as we know, that matter is discontinuous and atomic. It therefore lies within the range of comprehension. This, to the writer, appears as a very encouraging thing. It shows that we are equipped to think about one of the fundamental constituents of reality.

This is also true, as we have seen, of energy. Radiation from atomic electron jumps, does not take place in a continuous formless stream, but in definite discrete bundles.

And in conclusion we can reiterate what we suggested in the beginning of this chapter: That evolution of mind is infinite in possibility. It may even be that when the time comes, the intellect will have so changed and strengthened that even First Causes will not be beyond its ken.